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A Game-theoretic Model of International Climate Negotiations

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Global climate change, resulting from the global accumulation of heat-trapping greenhouse gases, has not only become a dominant environmental issue, it is becoming a defining international and social issue. Not only does the prospect of global climate change present potential environmental changes on a scale not seen in recorded history, but the challenges for international social order are unprecedented. Never before in the history of international relations have the nations of the world been confronted with an environmental risk with implications that are so far-reaching in both space and time. And with the sweeping past and prospective inequalities around the world in wealth and human welfare that are somehow connected to the problem of climate change, other international social issues begin to pale in comparative significance.

Exactly why the nations of the world have had difficulty in reaching agreement on limiting greenhouse gas emissions is something of a puzzle. An economic argument can be made that the world will continue to grow wealthier, as it has for centuries,[1] so that reducing greenhouse gas emissions now to avoid climate impacts in the future would essentially be transferring wealth to an even wealthier future generation.[2] However, there are non-trivial

[1] Most integrated assessment models—models that link a model of greenhouse gas emissions and climate change with a model of economic activity—build in fairly standard models of economic growth, which most economists believe will continue even in the face of a changed climate. Thomas Sterner & U. Martin Persson, *An Even Sterner Review: Introducing Relative Prices into the Discounting Debate*, 2 REV. ENVTL. ECON. & POL'Y 61, 63 (2008) ("Most economists, including Stern, appear to believe we will have much higher incomes in the future, despite climate change. But the risk of perhaps being only eleven—instead of thirteen—times as rich in the year 2200 is unlikely to get many people upset about climate change."); *see also* WILLIAM NORDHAUS, A QUESTION OF BALANCE 108 (2008) ("First, the model assumes continued rapid economic growth in the years ahead, although with slightly slower growth than over the past four decades."). Nicholas Stern, in his widely discussed commissioned report, is less transparent about his assumptions regarding economic growth, but he clearly believes that economic growth will continue even in the face of climate change (assuming that catastrophes do not cripple economies). *See* NICHOLAS STERN, STERN REVIEW ON THE ECONOMICS OF CLIMATE CHANGE 35 fig.2.3 (2007) [hereinafter STERN REVIEW] (showing a conceptual graph of economic growth paths, with a higher long-term growth path if greenhouse gas mitigation is undertaken), *available at* http://www.hm-treasury.gov.uk/stern_review_report.htm.

[2] This argument was first and most eloquently made by Nobel Laureate and economist Thomas Schelling. Schelling, *Intergenerational Discounting*, 23 ENERGY POL'Y 395 (1995).

risks that the effects of climate change will be catastrophic, and if the current rates of climate change continue, future generations will face a significant and continuing loss in average welfare.[3] For one thing, as higher global temperatures increasingly degrade environmental quality, the marginal value of environmental quality increases, making further environmental deteriorations more costly than typically estimated by economic models.[4] But more frighteningly, global climate change is alone among environmental problems in posing the risk of such vast environmental changes that the effects could destabilize entire economies, countries, and regions. Some studies of future climate impacts project some dire possibilities: global consumption could fall to less than 1 percent of current levels.[5] This is not future generations doing without four-terabyte iPods; this is future generations in developed countries having to queue up for food and drinking water. Economist Martin Weitzman has observed that even if the probability of these kinds of outcomes is quite small, some precautions might be warranted, even if they might not *seem* warranted under traditional cost-benefit analyses.[6]

Even a small risk of such calamity should be enough to compel the nations of the world to agree to some fundamental, and in many cases ridiculously cheap, ways of reducing greenhouse gas emissions.[7] Robust insurance markets exist for risks far less

[3] *See* Martin L. Weitzman, *On Modeling and Interpreting the Economics of Catastrophic Climate Change*, 91 REV. ECON. & STAT. 1 (2009).

[4] *See* Sterner & Persson, *supra* note 1, at 62.

[5] Most notably, twenty-two studies reviewed by the Intergovernmental Panel on Climate Change, a United Nations-appointed body, *see infra* note 11, have been the basis of much economic discussion, and have formed a de facto set of baseline projections. The projections have been used by a number of economists considering the costs and benefits of reducing greenhouse gas emissions, including William Nordhaus and Nicholas Stern, two prominent representatives of polar viewpoints on the costs and benefits of greenhouse gas reduction. *See generally* NORDHAUS *supra* note 1; STERN REVIEW, *supra* note 1. These studies are most carefully reviewed, however, by Martin Weitzman. *See* Weitzman, *supra* note 3.

[6] *See* Weitzman, *supra* note 3, at 13 (drawing upon twenty-two studies reviewed by the I.P.C.C. in its report, *see infra* note 11, and adding some analysis of possible positive feedback effects, following Torn and Harte, *see infra* note 13.

[7] Many energy efficiencies would not only reduce emissions, but more than pay for themselves. A recent report by the consulting firm McKinsey & Company found that, of forty greenhouse gas abatement strategies studied, seventeen had a negative cost, meaning that they represent net gains independent

important than the risks of cataclysmic climate change. So why are the nations of the world seemingly unable to come together to collectively buy a small amount of insurance?

Political economy arguments are obviously compelling. It is not news that industry-based interest groups can hijack an entire polity and prevent it from pursuing its own best collective interests. On climate change, some industries and interest groups have used a variety of political and psychological means to stall regulation of greenhouse gases.[8] But even assuming the most craven industrial self-interests, the risk of catastrophe and the fact that these industries and interest groups are exposed to the same risks as everyone else seem to suggest that political economy explanations alone are insufficient to explain the collective paralysis.

Another common account is that the transaction costs of solving such a monumental collective action problem are simply too great to overcome.[9] However, the transaction costs of negotiation are not, in fact, prohibitively large, especially given the fact that an international framework has been in place for nearly two decades, and fifteen subsequent international negotiating rounds have been held to hammer out agreements. Given the magnitude of the risk, and the availability of institutions for negotiating international agreements, a transaction cost explanation seems unsatisfying.

This Article argues that a new theory of international climate change negotiations is needed, and draws upon economic game theory to supply one. A number of papers have applied game

of their greenhouse gas-reducing potential. MCKINSEY & CO., PATHWAYS TO A LOW-CARBON ECONOMY 7 ex. 1 (2009). For example, an estimated three trillion cubic feet of natural gas is lost to leakage each year. Sealing leaks is believed to largely pay for itself by saving natural gas. Andrew C. Revkin & Clifford Krauss, *Curbing Emission by Sealing Gas Leaks*, N.Y. TIMES, Oct. 15, 2009, at A1. Total leakage from fossil fuel extraction and distribution builds about 4 percent of global greenhouse gas emissions annually. STERN REVIEW, *supra* note 1, at 275 box 12.3.

8 For example, ExxonMobil and a number of other firms have contributed to a campaign that highlights, in a misleading fashion, the scientific uncertainties of climate change and the human contributions to climate change. *See infra* notes 43–44 and accompanying text.

9 *See, e.g.*, Scott Barrett, *Climate Treaties and the Imperative of Enforcement*, *in* THE ECONOMICS AND POLITICS OF CLIMATE CHANGE 79 (Dieter Helm & Cameron Hepburn eds., 2009); TODD SANDLER, GLOBAL COLLECTIVE ACTION 223–25 (2004).

theory to the problem of international climate negotiations.[10] This is an obvious fit, since international climate negotiations are strongly driven by strategic interdependencies. What China will do with respect to greenhouse gas emissions depends critically on what the United States will do. What developing countries are willing to commit depends critically on what the developed nations of the world are willing to commit. The existing game-theoretic literature, however, has tended to model one strategic interaction at a time. This Article sets forth a more general, and yet simpler, model, one that can be tweaked to model a number of different strategic interactions. In that sense the model in this Article aims to be more fundamental and more general than previous game-theoretic modeling exercises in international climate negotiations.

Part I of this Article introduces the problem of climate change and the response, and suggests that the response has been puzzlingly inadequate. Part II presents some possible approaches to explaining the failure of countries to agree to reductions in greenhouse gases, including the game-theoretic approach adopted by this Article. Part III sets out some of the idiosyncrasies of the climate change problem, explaining the challenges they pose for modeling international climate negotiations. Part IV sets out the proposed model. Part V undertakes the bulk of the analysis in this Article: given a simple game-theoretic model, what happens when

[10] For some of the game-theoretic treatments to date see SCOTT BARRETT, ENVIRONMENT AND STATECRAFT (2005); Barbara Buchner & Carlo Carraro, *Parallel Climate Blocs: Incentives to Cooperation in International Climate Negotiations*, *in* THE DESIGN OF CLIMATE POLICY (Roger Guesnerie & Henry Tulkens eds., 2009); Parkash Chander & Henry Tulkens, *Cooperation, Stability, and Self-Enforcement in International Environmental Agreements*, *in* THE DESIGN OF CLIMATE POLICY (Roger Guesnerie & Henry Tulkens eds., 2009); SANDLER, *supra* note 9; Carlo Carraro & Domenico Siniscalco, *Strategies for the International Protection of the Environment*, 52 J. PUB. ECON. 309 (1993); William D. Nordhaus & Zili Yang, *A Regional Dynamic General-Equilibrium Model of Alternative Climate Change Strategies*, 86 AM. ECON. REV. 741 (1996); Carlo Carraro & Francesca Moriconi, *International Games on Climate Change Control* (Fondazione Eni Enrico Mattei, Working Paper No. 1988.022, 1998), *available at* http://www.feem.it/userfiles/attach/Publication/NDL1998/NDL1998-022.pdf; Steven Stoft, *Game Theory for Global Climate Policy* (Global Energy Policy Ctr., Research Paper No. 10-04, 2010), *available at* http://www.global-energy.org/lib/2010/ge1004-climate-game-theory-background-stoft.pdf; Peter John Wood, *Climate Change and Game Theory* (Environmental Economics Research Hub, Research Report No. 62, 2010), *available at* http://www.crawford.anu.edu.au/research_units/eerh/pdf/EERH_RR62.pdf, and see also the WITCH Model discussed *infra* at note 52.

the few parameters of the model are perturbed or the assumptions relaxed? This kind of modeling sensitivity analysis is the key to understanding some behaviors in the international climate arena. Part VI offers some concluding remarks.

INTRODUCTION: THE PROBLEM AND THE RESPONSE

Sobering scientific projections are reported in the Fourth Assessment of the Intergovernmental Panel on Climate Change (IPCC), released in 2007.[11] Not yet accounting for some positive feedback mechanisms that may make the projections too optimistic (and which more recent evidence suggests are more likely and more troubling than previously thought[12]), the IPCC's mean estimate of the increase in global average temperatures by the end of the century is an increase of 3° C, but it warns that a temperature rise of more than 4.5° C "cannot be excluded."[14] Indeed, some peer-reviewed studies cited by the IPCC in its Fourth Assessment report consider the possibility of much higher temperature increases, giving rise to temperatures that exceed the ranges of temperatures ever experienced by human civilization.[15]

There are a number of potentially cataclysmic effects of climate change, and almost all of them are global threats. They include a rise in sea levels,[16] inundating coastal areas and

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[11] INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, *Summary for Policymakers*, *in* CLIMATE CHANGE 2007: THE PHYSICAL SCIENCE BASIS; CONTRIBUTION OF WORKING GROUP I TO THE FOURTH ASSESSMENT REPORT OF THE INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE (S. Solomon, D. Qin, M. Manning, Z. Chen, M. Marquis, K.B. Averyt, M.Tignor & H.L. Miller eds., Cambridge Univ. Press 2007) [hereinafter FOURTH ASSESSMENT], *available at* http://www.ipcc.ch/pdf/assessment-report/ar4/wg1/ar4-wg1-spm.pdf. The IPCC is a United Nations-appointed body of hundreds of scientists engaged in the science of climate change. INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, www.ipcc.ch (last visited Oct. 24, 2010). Though often criticized, the IPCC was awarded the Nobel Peace Prize, along with former U.S. Vice President Al Gore, in 2007.

[12] Margaret S. Torn & John Harte, *Missing Feedbacks, Asymmetric Uncertainties, and the Underestimation of Future Warming*, 33 GEOPHYSICAL RES. LETTERS, at L10703 (2006).

[14] FOURTH ASSESSMENT, *supra* note 11, at 65.

[15] STERN REVIEW, *supra*, note 1, at 9 (studies summarized in box 1.2).

[16] ROBERT HENSON, THE ROUGH GUIDE TO CLIMATE CHANGE 111–17 (2d ed., 2008).

endangering trillions of dollars of real estate.[17] Coastal cities in affluent societies could, at considerable cost, insulate themselves by erecting sea walls, but many places in the world cannot afford such a fix.

Another worrying effect of climate change is a change in rainfall patterns so that parts of the world experience increased frequency and severity of droughts.[18] While the total amount of rainfall worldwide should not change substantially, where and when it falls may change enough to severely disrupt local or regional weather patterns and the ability of some regions to store and utilize water. Again, some measures can be taken to minimize the costs, such as increased storage and more efficient utilization of water, but there is only so much that human societies can do without adequate supplies of water. Decreased precipitation leading to loss of glacial mass will also jeopardize economies built on hydroelectric power fed by glacial runoff.[19] The flipside of the water shortage problem is the probable increase in the frequency of severe storm events,[20] which will challenge the ability of many countries to rescue their populations from calamity. While the U.S. learned some lessons in the aftermath of Hurricane Katrina, an increase in the number and severity of hurricanes may again make a mockery of American disaster relief efforts. One wonders what countries such as Indonesia and Bangladesh would do. And none of this accounts for effects on vital ecosystems, such as wetlands and oceans, which play important yet poorly-understood roles in regulating climate.

In short, the problem with climate change is that it threatens so many systems globally. The breadth of risk and the scope of

[17] TIM LENTON, ANTHONY FOOTITT & ANDREW DLUGOLECKI, MAJOR TIPPING POINTS IN THE EARTH'S CLIMATE SYSTEM AND CONSEQUENCES FOR THE INSURANCE SECTOR 76–77 (2009), *available at* http://knowledge.allianz.com/nopi_downloads/downloads/TP_Final_report.pdf.

[18] HENSON, *supra* note 16, at 59.

[19] In British Columbia, for example, the Energy Plan aims to ensure that clean energy, including hydroelectric power, accounts for over 90 percent of the province's electricity consumption. *See* BRITISH COLUMBIA MINISTRY OF ENERGY, MINES AND PETROLEUM RESOURCES, THE BC ENERGY PLAN: A VISION FOR CLEAN ENERGY LEADERSHIP 3 (2007), *available at* http://www.energyplan.gov.bc.ca/PDF/BC_Energy_Plan.pdf.

[20] FOURTH ASSESSMENT, *supra* note 11, at 782–84; *see also* HENSON, *supra* note 16, at 130, 135 (discussing growing evidence of an increase in number of intense hurricanes and typhoons).

potential changes to the biosphere threaten huge and possibly critical ecosystems and key components of the Earth's fundamental life systems. The risk posed by climate change is truly global, and affects every individual on the planet.

None of this is news to international diplomats and lawmakers. Efforts to address climate change have been underway for nearly two decades. The 1992 United Nations Framework Convention on Climate Change, an international agreement to agree, contemplated the subsequent negotiation of more concrete and more binding agreements. Only the third Conference of Parties, however, produced anything resembling an agreement to reduce emissions: the Kyoto Protocol.[21] The Kyoto Protocol sets out a schedule of emissions reductions for the world's developed countries, the only concrete expectations that have been expressed with respect to reducing emissions. Yet, Kyoto has been the subject of intense criticism for a number of flaws,[22] including its lack of any obligations for developing countries[23] (a major reason for reluctance on the part of the U.S. to commit to binding emissions reductions targets),[24] its perverse incentive to

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[21] Kyoto Protocol to the United Nations Framework Convention on Climate Change, Dec. 11, 1997, U.N. Doc FCCC/CP1997/L.7/Add. 1, 37 I.L.M. 22 (1998), *available at* http://unfccc.int/resource/docs/convkp/kpeng.pdf.

[22] *See, e.g.*, DAVID G. VICTOR, THE COLLAPSE OF THE KYOTO PROTOCOL AND THE STRUGGLE TO SLOW GLOBAL WARMING 24 (2001) (criticizing the Kyoto Protocol for being too costly and for harming national democracies); William D. Nordhaus, *After Kyoto: Alternative Mechanisms to Control Global Warming*, 96 AM. ECON. REV. 31 (2006) (arguing global harmonized GHG taxes are better for emissions control than the Kyoto Protocol's country-specific limits); Stephen M. Gardiner, *The Global Warming Tragedy and the Dangerous Illusion of the Kyoto Protocol*, 18 ETHICS & INT'L AFF. 23 (2004) (arguing the Kyoto Protocol failed to sufficiently take into account interests of future generations); Sheila M. Olmstead and Robert N. Stavins, *An International Policy Architecture for the Post-Kyoto Era*, 96 AM. ECON. REV. 35 (2006) (arguing the Kyoto Protocol imposed higher costs than would result from long term targets that reduced emissions less in the short term and more in the long term than Kyoto).

[23] *See* RICHARD B. STEWART & JONATHAN B. WIENER, RECONSTRUCTING CLIMATE POLICY 88–89 (2003).

[24] President Obama, who had sought federal climate change legislation in the U.S., said the following in Copenhagen:

> "[W]hat's happened obviously since 1992 is that you've got emerging countries like China and India and Brazil that have seen enormous economic growth and industrialization. So we know that moving forward it's going to be necessary if we're going to meet those targets for some changes to take place among those countries. *It's not enough just for the developed countries to make changes. Those countries are going to have to make some changes, as well*—not of the same pace,

discourage the meaningful post-Kyoto participation of developing countries,[25] and, most of all, its lack of any sanctions for noncompliance.[26] Because failing to meet Kyoto's country-specific emissions targets carries no sanctions, there has been no incentive to actually comply with the Kyoto Protocol. Canada, for example, ratified the Kyoto Protocol in 2002, committing to a 6 percent reduction in its greenhouse gas emissions from 1990 levels, and then continued on its trajectory of increasing its greenhouse gas emissions, so that in 2005 it emitted 25 percent *more* in CO_2-equivalent emissions[27] than it did in 1990.[28] And

> not in the same way, but they're going to have to do something to assure that whatever carbon we're taking out of the environment is not just simply dumped in by other parties."

Barack Obama, President of the U.S., Remarks by the President during Press Availability in Copenhagen (Dec. 18, 2009) (emphasis added), *available at* http://www.whitehouse.gov/the-press-office/remarks-president-during-press-availability-copenhagen. *See also* Lisa Friedman, *Potholes in the Road to Copenhagen Grow in Bangkok Talks*, CLIMATEWIRE, Oct. 9, 2009 (discussing "America's terms" that "[m]ajor developing nations must make legally binding commitments to temper their own global warming pollution").

[25] Steven Stoft, *The Cause of the War over Caps and How to End It*, GLOBAL ENERGY POLICY CENTER 1 (2009), *available at* http://ssrn.com/abstract=1427665 (pointing out that the cap-and-trade program under Kyoto, along with the Clean Development Mechanism, creates a strong disincentive for developing countries to commit to a future national cap in a post-Kyoto regime).

[26] *See* BARRETT, *supra* note 10, at 360–62 ("[The] Kyoto Protocol is unlikely to sustain meaningful cooperation. This is not for the reasons usually given—that Kyoto will do little to moderate climate change, that monitoring of the agreement will be imperfect, that its mechanisms are too complicated, and that its implementation will be too costly—though these criticisms are also valid. The main strike against Kyoto is the most crucial of all: the agreement fails to solve the enforcement problem.").

[27] CO_2-equivalent emissions, or carbon dioxide-equivalents, represent an index of total emissions from all six greenhouse gases regulated under the Kyoto Protocol, which include carbon dioxide, methane, nitrous oxides, hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. The index is weighted by the heat-trapping effect of emissions of the different greenhouse gases, in comparison with the effect of a ton of carbon dioxide. For example, since methane has twenty-one times the heat-trapping power of carbon dioxide, emissions of methane are multiplied by twenty-one for purposes of calculating the index. Also, in terms of emissions trading under Kyoto, emissions of methane will be deemed to be twenty-one times as important as the equivalent emissions of carbon dioxide. *See, e.g.*, U.S. ENVTL. PROT. AGENCY, EMISSION FACTS: METRICS FOR EXPRESSING GREENHOUSE GAS EMISSIONS: CARBON EQUIVALENTS AND CARBON DIOXIDE EQUIVALENTS (2005), *available at* http://www.epa.gov/oms/climate/420f05002.htm (discussing use of carbon dioxide equivalent metric).

[28] ENVIRONMENT CANADA, NATIONAL INVENTORY REPORT 3 (2007),

with no means of controlling emissions leakage—the transfer of emissions from countries that regulate or price greenhouse gas emissions to countries that do not—Kyoto offers no assurances to countries undertaking costly mitigation measures that their efforts will be effective. Although negotiations in Copenhagen last year did yield a monitoring and "transparency" agreement among some important emitters—most notably the U.S., China, India, and South Africa—it did not, as had been long planned, produce a successor treaty to Kyoto. Most significantly, Kyoto has not actually delivered any significant emissions reductions.[29]

I. WHY HAVE INTERNATIONAL EFFORTS FAILED?

The question is not why the U.N. Framework Convention on Climate Change and the Kyoto Protocol are failures in the international legal sense. The question is rather why international efforts at negotiation have produced such flawed efforts. International agreement, especially among countries that are so diversely situated, is always difficult. And this is not to say that as a normative matter, the world is unambiguously better off if cooperation is achieved in reducing greenhouse gas emissions. But given the *apparent* stakes, the puerile behavior and bombastic posturing of the world's leaders and negotiators is a head-scratcher.[30] This Article undertakes the descriptive task of

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available at http://www.ec.gc.ca/Publications/default.asp?lang=En&xml= E80FB0A6-A0C2-4E6E-A12E-005D50D041C5. This precludes Canada from realistically being able to comply with its Kyoto mandate of reducing its emissions to 6 percent below 1990 levels, or 560 megatons.

[29] Greenhouse gas emissions tend to track economic activity, which declines during economic downturns, such as the one in 2008 and 2009. *See, e.g.*, U.S. ENERGY INFO. ADMIN., SHORT-TERM ENERGY OUTLOOK SUPPLEMENT: UNDERSTANDING THE DECLINE IN CARBON DIOXIDE EMISSIONS IN 2009, at 1 (2009) (reporting expected 5.9 percent decline from 2008); Press Release, U.S. Energy Info. Admin., U.S. Greenhouse Gas Emissions Decreased by 2.2 Percent in 2008 (Dec. 3, 2009), *available at* http://www.eia.doe.gov/neic/press/press333 html. As of 2007, one year before the Kyoto compliance period of 2008–2012, world carbon dioxide emissions were 30.56 gigatons. *Climate Analysis Indicators Tool*, WORLD RESOURCES INST., http://cait.wri.org (last visited May 24, 2011) (obtained by dividing China's emissions by its fraction of world total). In 1997, the year of the signing (not ratification) of the Kyoto Protocol, world emissions were 23.64 gigatons. *Id.* (obtained by dividing the United States' emissions by its fraction of the world total).

[30] For example, during negotiations at the Copenhagen conference of parties, Chinese Premier Wen Jiabao snubbed world leaders by sending an aide instead of attending in person, prompting President Obama to raise his voice to the

explaining why cooperation has been elusive.

One explanation that has been offered for the failure of international climate negotiations is that climate change is a massive collective action problem, and the transaction costs of finding agreement on greenhouse gas emissions reductions are too great.[31] A simple economic account of the climate change problem would be that because the benefits of emitting greenhouse gases are internalized within a country, but the costs spread out among the entire world (albeit at different levels of harm across countries and socioeconomic strata), emitting greenhouse gases is an over-supplied activity. Correcting the oversupply problem, however, is challenged by the costs of organizing negotiations, and actually undertaking those negotiations. But this explanation would seem to fall short, as the UNFCCC and the Kyoto Protocol, while flawed, at least reduce the transaction costs of organizing and negotiating. These institutions change the outcomes of uncooperative games so that cooperation becomes not only possible, but likely.[32] Coasean bargaining only succumbs to transaction cost problems if the transaction costs exceed the potential gains from trade. Insuring against the large risks posed by climate change would seem to present large enough upsides to overcome the transaction costs of bargaining, at least those having to do with negotiation costs. If, on the other hand, strategic behavior is the problem, then this article proposes an analytical way forward.

More compelling might be a political economy explanation focusing on the domestic politics of climate change. Domestic politics can greatly complicate the task before international negotiators. The Byrd-Hagel resolution, a non-binding "sense of the Senate" resolution, declared that the United States should not be a party to any agreement to reduce emission that would not also

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Premier, asking, "Mr. Premier, are you ready to see me?" Peter Maer, *Impromptu Moments Shaped Copenhagen Accord*, CBS NEWS, Dec. 20, 2009, http://www.cbsnews.com/stories/2009/12/20/politics/main6000506.shtml.

[31] *See* SANDLER, *supra* note 9, at 223–25; Barrett, *supra* note 9, at 79; Daniel H. Cole, *Climate Change and Collective Action*, 61 CURRENT LEGAL PROBS. 2008 229, 231–32 (2009) (suggesting collective action problem impedes negotiation of effective climate change agreements).

[32] *See* Daniel H. Cole & Peter Z. Grossman, *Institutions Matter! Why the Herder Problem Is not a Prisoner's Dilemma*, 69 THEORY & DECISION 219, 223–24, 226 (2010) (explaining that "institutions shape the payoffs, incentives, and dominant strategies of players in all games").

require emissions reductions of developing countries.[33] That resolution certainly complicated the efforts of American climate change negotiators. In 2009, with a Democratic President committed to climate change legislation, and a Democrat-controlled House of Representatives and Senate, climate change legislation passed the House of Representatives[34] only with enormous concessions extracted by a variety of sectors and populations.[35] In 2010, a similar Senate effort ended in failure in the wake of strong opposition to climate regulation,[36] a failure that has triggered blame from other countries for the disappointing progress made in post-Copenhagen negotiations.[37] This problem is not limited to democracies: even China, heretofore resistant to committing to binding greenhouse gas emissions limitations, sometimes has found it a challenge to speak with one voice.[38] China's stark divide between affluent regions vulnerable to climate change and poor regions interested only in economic growth has given rise to a division of opinion on how keenly the country wishes to pursue greenhouse gas mitigation policies.[39]

But even severe internal divisions within a country do not support a pure political economy explanation. For one thing, there would be the question of why those that have much to lose from climate change could not make a transfer payment to those, such as the oil and coal industries, that are opposed to greenhouse gas

33 S. Res. 98, 105th Cong. (1997).

34 American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (2009) (Waxman-Markey Bill).

35 For one of many analyses of the Waxman-Markey bill and the political concessions that were made in order to obtain passage, see Shi-Ling Hsu, Nine Reasons to Adopt a Carbon Tax 9 (May 17, 2009) (unpublished manuscript), *available at* http://papers.ssrn.com/sol3/papers.cfm?abstract_id=1405944.

36 *See* Robin Bravender & Katie Howell, *Reid Pronounces Climate Bill Dead, Sees Hope for Energy Bill*, GREENWIRE, Sept. 8, 2010, http://www.eenews net/Greenwire/print/2010/09/08/4.

37 Lisa Friedman, *U.S. Accuses Countries of 'Walking Back' from Copenhagen Accord*, CLIMATEWIRE, Aug. 9, 2010, http://www.eenews net/ climatewire/print/2010/08/09/5.

38 *See* Edward Wong & Jonathan Ansfield, *China Insists That Its Steps on Climate Be Voluntary*, N.Y. TIMES, Jan. 30, 2010, at A5 (noting that while a Chinese negotiator at Copenhagen publicly scolded President Obama and wagged his finger at Obama, Chinese Prime Minister Wen Jiabao told the interpreter to ignore the official's remarks).

39 Daniel Abebe & Jonathan Masur, *International Agreements, Internal Heterogeneity, and Climate Change: The Two Chinas Problem*, 50 VA. J. INT'L. L. 325 (2010).

regulation. After all, the 2009 American Clean Energy and Security Act (or Waxman-Markey, after the bill's sponsors)[40] included lavish legislative giveaways to coal-burning electric utilities and other industries that would be negatively affected by greenhouse gas regulation.[41] Transfer payments could even be transnational—they could flow from those with much to lose to those that prefer economic development *in another country*. The Kyoto Protocol has "flexibility mechanisms" such as the Clean Development Mechanism, which provides for developed-country funding of projects in developing countries that supposedly reduce greenhouse gas emissions. While the Clean Development Mechanism has come under intense criticism for not actually producing emissions reductions,[42] it still stands as evidence that transnational transfer payments are possible, and even institutionalized, within the UNFCCC framework.

A second reason that a political economy explanation seems to fall short is that the threats of climate change are global, and no one will be spared at least some serious ill effects. It may be true that a personal cost-benefit analysis of whether one would favor greenhouse gas mitigation at some personal cost would be vastly different for differently-situated individuals throughout the world, but climate change is not a trifling matter for anyone. And yet the way that some interests seem to treat the issue suggests that the impacts of climate change are irrelevant. The way that oil companies and some other industries cravenly manipulated public opinion in order to sow doubt about the scientific consensus regarding climate change[43] evinces little regard for a dangerous truth that will ultimately affect these firms as much as others. For example, political economy explanations do not explain the

[40] American Clean Energy and Security Act of 2009, H.R. 2454, 111th Cong. (2009).

[41] The "grandfathering" of tradable emissions permits under Waxman-Markey, or the free allocation of permits, was worth an estimated $378 billion. 35 percent of the grandfathered permits were allocated to electric utilities. Hsu, *supra* note 35, at 9.

[42] *See, e.g.*, Michael W. Wara & David G. Victor, *A Realistic Policy on International Carbon Offsets* (Program on Energy and Sustainable Dev. at Freeman Spogli Inst. for Int'l Studies, Stanford Univ., Working Paper No. 74, 2008), *available at* http://iis-db.stanford.edu/pubs/22157/WP74_final_final.pdf.

[43] *See* Aaron M. McCright & Riley E. Dunlap, *Defeating Kyoto: The Conservative Movement's Impact on U.S. Climate Change Policy*, 50 SOC. PROBS. 348 (2003).

difference between the approach taken by two of the largest integrated petroleum products firms in the world: BP, which sought to embrace a low-carbon future early on, and Exxon Mobil, one of the leading opponents of greenhouse gas regulation and a source of funding for detractors of climate change science.[44] It could well be that some firms, such as Exxon Mobil, would benefit from a respite from greenhouse regulation to give them some time to diversify their corporate investments into lower-carbon industries. But on some level, even these firms must recognize that the heroic measures that they are undertaking to derail greenhouse gas regulation and foil global cooperation poses a threat to the entire planet, including the firms themselves, which, unlike human beings, could live on indefinitely. There is something else going on other than a simple self-interested gerrymandering of public policy.

A final possible explanation emerges from new research on the psychological aspects of climate change, which suggests that people simply may not believe that climate change is truly a problem or a risk.[45] If this is the case, then a proper response would include a fairly radical set of public policies aimed at public outreach and education, bridging a gap between what scientists know and what the public knows. But this explanation also leaves questions unanswered: do our national leaders and international negotiators believe that climate change presents a serious risk? If

[44] For an analysis comparing Exxon Mobil and BP Amoco, see Ian H Rowlands, *Beauty and the Beast? BP's and Exxon's Positions on Global Climate Change*, 18 ENV'T & PLAN. C: GOV'T & POL'Y 339 (2000); Ingvild Andreassen Sæverud & Jon Birger Skjærseth, *Oil Companies and Climate Change: Inconsistencies Between Strategy Formulation and Implementation?*, 7 GLOBAL ENVTL. POL. 42 (2007). Exxon has funded the Global Climate Coalition, which uses tactics similar to those used by tobacco companies to sow doubt that smoking leads to lung cancer. UNION OF CONCERNED SCIENTISTS, SMOKE, MIRRORS & HOT AIR: HOW EXXONMOBIL USES BIG TOBACCO'S TACTICS TO MANUFACTURE UNCERTAINTY ON CLIMATE SCIENCE 9 (2007).

[45] *See* ANTHONY LEISEROWITZ, U.N. DEV. PROGRAMME, HUMAN DEV. REP. 2007/2008: PUBLIC PERCEPTION, OPINION, AND UNDERSTANDING OF CLIMATE CHANGE – CURRENT PATTERNS, TRENDS, AND LIMITATIONS 7, 14–15 (2008), *available at* http://hdr.undp.org/en/reports/global/hdr2007-2008/papers/leiserowitz_anthony.pdf; *see also* Elke U. Weber, *Experience-based and Description-based Perceptions of Long-term Risk: Why Global Warming Does Not Scare Us (Yet)*, 77 CLIMATIC CHANGE 103, 103–04 (2006) ("The absence of a visceral response on part of the public to the risks posed by global warming may be responsible for the arguably less than optimal allocation of personal and collective resources to deal with this issue.").

so, then why do they negotiate with each other—fellow believers, presumably—rather than try to change the public perceptions of climate change? If not, then why would they bother with the elaborate charade of appearing to try to negotiate an international solution? With respect to national leaders and international negotiators, either they believe it or they don't, but if the problem is the public psychology and perception of climate change, the current path of negotiations is not a sensible response.

None of the above explanations for the failure to reach agreement on an international solution pays attention to the strategic interactions among countries as individual players. Undoubtedly, there are political economy issues, transaction cost issues, and issues of political will tied to psychological obstacles to recognizing the danger from climate change. But in the end, the problem that seems to animate international climate negotiations most is the problem of one country waiting to see what another country will do, because what countries do profoundly affects the decision environment for other countries. Climate change is a collective action problem writ large; only in a cooperative outcome in which costly mitigation is undertaken is cooperating even remotely rational. Without reassurances from other countries of cooperation, it is extremely difficult to undertake a cooperative course of action.

In the vernacular of international relations theory, this article takes a realist approach to explaining climate negotiations, working from very simple assumptions that countries are self-interested and rational.[46] This is not to deny that alternative intellectual approaches would have much to say about climate negotiations, especially in examining the complexities of domestic politics and how they affect international negotiations. However, the question addressed by this Article is fundamentally a realist

[46] Realism in international relations theory assumes that states are self-interested rational actors and will pursue national interests. By contrast, a number of rival theories have challenged the simplicity of realism, including a "constructivist" school that has sought to focus on non-state actors that influence global events and international politics, and a "neoliberal institutionalist" school that focuses on the role of institutions as facilitators of relations among states. For a review of the major theories in international law and international relations, see Peter J. Katzenstein, Robert O. Keohane & Stephen D. Krasner, *International Organization and the Study of World Politics*, 52 INT'L ORG. 645 (1998); Harold Hongju Koh, *Why Do Nations Obey International Law?*, 106 YALE L.J. 2599 (1997).

one: why are states seemingly behaving irrationally, and not pursuing their national self-interests? Doubtless many theories could provide some explanation, but in light of the interdependencies that seem to animate international climate negotiations, this Article seeks to provide a realist explanation for what appears to be anomalous behavior.

This Article draws upon economic game theory, modeling state actors as individual players. Game-theoretic models of climate strategies have previously been developed to model international climate negotiations. In *Environment and Statecraft*, Scott Barrett sets out some principles of a theory on what would make for successful international agreement to reduce greenhouse gases.[47] Drawing extensively on game theory, Barrett concludes that the way to solve the twin problems of participation and enforcement that have plagued Kyoto is first to agree to research and development funding to lower the costs of greenhouse gas reduction, and second to agree to technological standards—command-and-control regulation—of greenhouse gas reduction so as to create network incentives for adoption.[48] Joining the agreement would be, like the adoption of Microsoft Windows, an economic necessity. Barrett has, in his subsequent work, further developed his theory on technological development as the subject of a treaty, showing that promoting some technologies as part of a treaty may, under certain circumstances, induce greater cooperation.[49] This would be true if there existed a technology that could produce positive network externalities, where adoption brings its own benefits—again, not unlike adopting something like Microsoft Windows. What is still missing from the economic literature, however, is a simple model that can accommodate a broad range of strategic behaviors of countries in climate negotiations.

Other game-theoretic models of climate negotiations have been incorporated into sophisticated economic models that devote many lines of code to simulating the optimal path of greenhouse gas mitigation for different countries over long periods of time.[50]

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47 BARRETT, *supra* note 10.

48 BARRETT, *supra* note 10, at 393–96.

49 Scott Barrett, *Climate Treaties and Backstop Technologies* 19 (CESifo, Working Paper No. 3003, 2010); *see also* Scott Barrett, *Kyoto and Beyond: Alternative Approaches to Global Warming*, 96 AM. ECON. REV. 22, 25 (2005).

50 These include the model in Nordhaus & Yang, *supra* note 10, and the

These models typically divide the world into a handful of regions consisting of one or more countries—the United States and China are usually "regions" all by themselves[51]—and model the optimal amount of greenhouse gas abatement over time horizons of fifty to one hundred years. The World Induced Technical Change Hybrid model, or the WITCH model,[52] developed by researchers at the environmental economic research organization Fondazione Eni Enrico Mattei, incorporates a game-theoretic component into an integrated assessment model (a complex model that integrates economic activity and climate feedbacks).[53] WITCH divides the world into twelve regions and models their behavior over a period of one hundred years, in five-year increments. The game-theoretic component, however, only involves game-theoretic decisions at two stages: a stage in which formations of coalitions are made among regions agreeing to reduce emissions, and a second stage in which an optimal emissions level is chosen by coalitions (countries acting in concert) and countries that did not join a coalition in the first stage.[54]

While these models delve deeply into economic forecasting, they do not test different game-theoretic assumptions and explore how outcomes might change as assumptions change. These

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WITCH model, discussed *infra* note 52.

[51] *See, e.g.*, Nordhaus & Yang, *supra* note 10, at 743 (William Nordhaus's early RICE model (Regional Integrated Model of Climate and the Economy) divided the world into ten regions: the U.S., China, the E.U., Japan, the former Soviet Union republics, India, Brazil, and Indonesia, i.e. 11 large countries, 38 medium-sized countries, and 137 small countries). *See also* WITCH model, *infra* note 52.

[52] The WITCH model (World Induced Technical Change Hybrid model) was developed by a number of Italian researchers. It divides the world into twelve regions: the U.S., China, Western E.U. countries, Eastern E.U. countries, Japan and Korea, South Asia, Southeast Asia, Latin America, Middle East and North Africa, Africa, Non-E.U. Eastern European countries, and Australia and New Zealand. WITCH builds in a number of features previously not a part of integrated assessment models, such as endogenous models of technological change. *See* WITCH MODEL DESCRIPTION, http://www.witchmodel.org/pag/model html (last visited Nov. 15, 2010); *see also* Valentina Bosetti et al., *International Climate Coalitions: A Game-Theoretic Analysis Using the WITCH Model* (Fondazione Eni Enrico Mattei, Working Paper No. 325, 2009), *available at* http://www.bepress.com/cgi/viewcontent.cgi?article=1336&context=feem.

[53] Integrated assessment models link climate change effects and economic activity and effects in a joint climate and economic model to project climate changes and economic costs and benefits together. For a review of some integrated assessment models, *see* STERN REVIEW, *supra* note 1, at 145–52.

[54] Bosetti et al., *supra* note 52, at 7.

models are heavy on the economic analytics, but light on the simpler game-theoretic interactions among countries that are frustrating progress towards negotiated solutions to the climate change problem.

This article proposes a simple dynamic game-theoretic model, with a view towards perturbing a number of assumptions in the model to see how outcomes might be affected. The complexity of the climate change problem is such that no single model can capture all of the strategic behaviors in play in international climate negotiations. What seems more useful is a simple model to highlight the most prevalent and important behaviors, and suggest some non-obvious policy directions.

II. GAME-THEORETIC MODELING CHALLENGES IN THE CLIMATE CHANGE CONTEXT

A model of international climate negotiations must address a number of issues specific to the climate change problem, or at least be explicit about its assumptions regarding these issues. In broad brush strokes, some of the idiosyncratic features of the climate change problem are as follows:

1. *The public good nature of greenhouse gas reductions.* Being a global phenomenon, the greenhouse effect provides a uniquely clear example of a public goods problem. Pure public goods are non-excludable in provision (once the good is provided to one it is necessarily provided to all) and non-rival in consumption (the enjoyment of one person of the good does not detract from the enjoyment by another).[55] Reductions of greenhouse gas emissions are *perfectly* non-excludable and non-rival. The reduction of emissions by one emitter or one country unavoidably inures to the benefit of everyone in the world (in the form of avoided risk and damages from climate change). Similarly, "consumption" of this benefit is necessarily enjoyed by everyone. As compared to many pollution and natural resource problems, the climate change problem provides a perfect example of a public good.

2. *Free-rider effects of mitigation.* A consequence of the public good nature of greenhouse gas emissions reduction is the strong potential for free-riding. Free-riding may take the form of

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[55] CHARLES D. KOLSTAD, ENVIRONMENTAL ECONOMICS 95–99 (2d ed. 2011).

avoiding costly mitigation while allowing others to undertake it, and it may also take the form of avoiding the costs of research and development of new technologies that reduce greenhouse gas emissions.

A particularly troublesome aspect of the free-riding problem is that the greater the amount of mitigation undertaken by a country (or group of countries), the greater the incentives for free-riding. Countries that reduce emissions will almost certainly be reducing fossil fuel consumption, which reduces the global price of fossil fuels, which in turn encourages developing countries to increase the use of fossil fuels, canceling out, to some extent, the emissions reductions achieved by developed countries, probably at great economic and political cost.

The implication of the free-riding problem is that action to reduce emissions may need to be universal or near-universal. As the Stern Review points out, no country or even group of countries can solve the climate change problem alone; coordinated action is absolutely necessary.[56] Countries thus find themselves in the position of knowing that their participation in an agreement to mitigate greenhouse gas emissions is a necessary, but far from sufficient, condition to the consummation of an effective international agreement to reduce emissions. This is a major distinction between the climate change problem and the problem of ozone-depleting chemicals, in which a smaller number of countries with dominant firms were able to kick-start a broad phase-out of ozone-depleting chemicals.[57]

Aggravating the free-riding problem is a political reality: if one country waits to mitigate, other countries will pay for that delay. If China continues to build coal-fired power plants, the costs of retiring them in the future will *not*, as a practical matter, be borne by China alone. Because such large greenhouse gas emitters as the U.S. and China hold the fate of the world in their hands, it is unlikely that their initial reluctance to act will be fully punished by other countries. Put more clearly in a multilateral context, if either China or the U.S. is initially recalcitrant, the domestic politics of both countries are such that it is unlikely that

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[56] Mitigation will require action from developed and developing countries. *See, e.g.*, STERN REVIEW, *supra* note 1, at 205–06.

[57] For a discussion of international dealings with respect to the problem of ozone depletion, see RICHARD ELLIOTT BENEDICK, OZONE DIPLOMACY (1998).

such recalcitrance will be fully punished by the rest of the world. In effect, the late-mitigating countries would be free-riding on the efforts of early-mitigating countries to develop technologies and processes that reduce emissions.

3. *Uncertainty regarding damages and adaptation costs.* Despite a tremendous worldwide research effort, and despite the efforts of the Nobel prize-winning Intergovernmental Panel on Climate Change, scientific uncertainty continues to pose problems with predictions. It is still not clear which effects will occur, where they will occur, when they will occur, and how serious they will be when and if they occur. At bottom, it is still difficult to relate concentrations of greenhouse gases to specific global temperature changes. The effects and formation of clouds, for example, is poorly understood.[58] Whether a near-catastrophic "burp" of methane previously locked up in Arctic boreal forests will occur, and how much of a temperature change that would induce, is unknown.[59] Even for what one would think to be a relatively straightforward projection, such as the extent of sea level rise, predictions are complicated by numerous uncertainties regarding the extent of ice melt that would pour massive quantities of fresh water into the oceans, the degree and nature of thermal expansion that would exacerbate sea level rises, and the extent to which carbon absorption by oceans would ameliorate warming effects.[60]

All of this uncertainty makes it difficult for present-day national governments to understand the future impacts of climate change, let alone communicate the risk to its citizenries and plan for their futures. And yet, if a country adopts a formal or de facto cost-benefit approach for deciding whether or not to undertake greenhouse gas emissions mitigation, this piece of information would seem to be indispensable. Rational policy becomes difficult to formulate, and more difficult to justify to an electorate.

One consequence of this uncertainty may be that as

[58] *See, e.g.*, Rong Zhang, Sarah M. Kang & Isaac M. Held, *Sensitivity of Climate Change Induced by the Weakening of the Atlantic Meridional Overturning Circulation to Cloud Feedback*, 23 J. CLIMATE 378 (2010); GODDARD INSTITUTE FOR SPACE STUDIES, SCIENCE BRIEFS - CLOUDS AND CLIMATE CHANGE: THE THICK AND THIN OF IT (2000), *available at* http://www.giss.nasa.gov/research/briefs/delgenio_03/.

[59] HENSON, *supra* note 16, at 86.

[60] *Id.* at 109–18.

information changes, a country's perception of its vulnerability to climate change may change. This is especially true in light of recent studies that have shown a considerable gap in understanding between climate scientists and the general public.[61] Disconcerting as it may be, a game-theoretic analysis will need to at least account for the possibility that a country's perception of its climate change damages may change over time.

4. *Discounting.* Even more so than many environmental and natural resource problems, the burdens of mitigation and the benefits of avoiding climate change are separated in time. While some of the effects of climate change are already being felt, the most serious effects are likely to occur in the very long term, fifty to two hundred years from now,[62] making cost-benefit analyses extremely sensitive to the discount rate (or rates) utilized. The complicated nature of this issue and the enormous economic implications have deeply divided economists. Most notably, Sir Nicholas Stern, who was commissioned by the U.K. government to perform a cost-benefit analysis of action to avoid climate change,[63] and Yale economist William Nordhaus, a leading developer of integrated assessment models, have disagreed sharply about the appropriate discount rate. The discount rate is a critical difference in the ways that the two prominent economists have analyzed the climate change problem and reached dramatically different conclusions.[64] The division has made for unusually entertaining theater for academics.[65]

Discounting as a purely economic concept is controversial enough; asking the additional question in a descriptive political

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[61] *See* LEISEROWITZ, *supra* note 45, at 18–20.

[62] *See, e.g.*, HENSON, *supra* note 16, at 15 ("If emissions continue to rise unabated through this century, the Greenland and/or West Antarctica ice sheets could be thrown into an unstoppable melting cycle that would raise sea levels by more than 7 m (23 ft) each. This process would take some time to unfold – probably a few centuries, although nobody can pin it down at this point . . . .").

[63] STERN REVIEW, *supra* note 1.

[64] A number of issues divide the two economists, but the issue of the appropriate discount rate seems to generate the most controversy. For a review of these disagreements, see Daniel H. Cole, *The Stern Review and Its Critics: Implications for the Theory and Practice of Cost-Benefit Analysis*, 48 NAT. RESOURCES J. 53, 60–78 (2008).

[65] Nordhaus has written that the Stern Review was essentially "political in nature and has advocacy as its purpose." William D. Nordhaus, *A Review of the Stern Review on the Economics of Climate Change*, 45 J. ECON. LITERATURE 686, 688 (2007).

context makes matters even more complicated. Almost anything that is decided in the climate change context, including the decision to do nothing, presents inter-generational tradeoffs. For purposes of developing a game-theoretic model, a discount rate must reflect not so much a normative judgment, but a positive description of countries' political behavior with respect to climate change. That is, how much will politicians discount the welfare of future generations, beyond what a purely economic analysis would call for? Even if this challenging question is not wrestled down to a conclusion, the sensitivity of payoffs to assumptions regarding the discount rate must be taken into account.

A final consideration is that delayed action, allowing concentrations to go higher before more drastic cuts are undertaken, poses risks of some irreversible ecological damages that are often overlooked.[66] It is also possible that certain irreversibilities in climate may take place while we are taking the time to study the problem. Irreversibility is the flipside of discounting, working in the opposite prescriptive direction. As a descriptive modeling matter, the model proposed in this Article does not explicitly assume that countries, in balancing costs and benefits of greenhouse gas mitigation, take account of irreversibilities.

5. *The savings in mitigation costs of early mitigation.* The less that is done in the near term to reduce emissions and begin the transition into lower-carbon economies, the more expensive it will be in the long run, *in nominal terms*, to do the same things. Despite their disagreements on discounting, Nicholas Stern and William Nordhaus both recommend gradually intensifying abatement effort over time to mirror the increasing social cost of greenhouse gas emissions.[67] Delaying action is very costly; once emissions rise to certain levels, the emissions cuts to lower greenhouse gas concentrations to manageable levels become extremely costly.[68] Again, these conclusions are sensitive to the

[66] *See, e.g.*, STERN REVIEW, *supra* note 1, at 72 (ocean acidification irreversibly disrupting marine ecosystems), 80 (loss of species), 81 (irreversible melting and collapse of ice sheets); *see also* Robert S. Pindyck, *Irreversibilities and the Timing of Environmental Policy*, 22 RESOURCE & ENERGY ECON. 233, 234 (2000).

[67] STERN REVIEW, *supra* note 1, at 302; NORDHAUS, *supra* note 1, at 16.

[68] STERN REVIEW, *supra* note 1, at 199 ("The rate of emissions cuts required to meet a stabilization goal is very sensitive to both the timing of the peak in

discounting assumptions.

It is certainly possible that technological development could lower future costs so that waiting is a rational strategy.[69] It is also true that the costs of carbon abatement are likely to fall over the next twenty years.[70] However, models of technological "learning" rates generally do not assume large jumps in technological innovation,[71] perhaps because they rarely occur. Thus, unless the discount rate is assumed to be very high, it becomes unlikely that waiting and delaying is an economically efficient response to climate change, as the decrease in costs is not likely to be as great as the increase in cost of delayed action. Here again, though, the free-riding problem figures prominently, as a country could rationally wait and allow other countries to undertake the expense of research and development of climate reduction technologies.

6. *The role of technology.* The rate of technological innovation is a wild card that complicates economic modeling and prescriptions for the optimal path of mitigation. Current developments of some technologies, such as carbon capture and storage technology[72] or biofuels,[73] have not been particularly encouraging.[74] But at the same time, other technologies have

global emissions, and its height. Delaying action now means more drastic emissions reductions over the coming decades."), 211 ("Without early, well-planned action, the costs of mitigating emissions will be greater.").

[69] *Id*, at 225–26.

[70] *Id.* at 231.

[71] *Id.* at 226 ("[E]stimates of learning rates from different technologies span a wide range, from around 3 percent to over 35 percent cost reductions associated with a doubling of output.").

[72] "Carbon capture" refers to the capture of carbon dioxide emitted as a result of any combustion process, while the storage stage refers to the permanent storage of the captured carbon dioxide, so that it does not enter the atmosphere and contribute to climate change. *See* Howard Herzog & Dan Golomb, *Carbon Capture and Storage from Fossil Fuel Use*, 1 ENCYCLOPEDIA ENERGY 277 (2004).

[73] Biofuels are gasoline substitutes that are derived from a variety of agricultural crops, such as corn and sugar. Although biofuels are burned in an internal combustion engine process like ordinary gasoline, the fact that biofuels obtain their carbon from the normal carbon uptake process of vegetation creates a net zero carbon dioxide emissions process. *See generally* Timothy Searchinger et al., *Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Changes*, 319 SCIENCE 1238 (2008).

[74] As recently as 2008, demonstration costs remained in the range of €60 to €90 per ton of CO_2 stored. This is approximately $88 to $131 per ton, using an exchange rate of €1.4637 to $1, the average rate for 2008. BANK OF CANADA, FIN. MARKETS DEP'T, YEAR AVERAGE OF EXCHANGE RATES (2008), *available at*

emerged as surprising challengers to the worldwide fossil fuel hegemony, such as concentrated solar power.[75] Whether the world sees more pleasant or unpleasant surprises may determine the fate of climate change.

In addition to its role in reducing emissions, technology has other, more complicated roles as well. How the world *adapts* to climate change, technologically and otherwise, may profoundly affect approaches to climate change.[76] A country's confidence in its ability to adapt to climate change may dampen its enthusiasm

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http://www.bank-banque-canada.ca/pdf/nraa08.pdf; MCKINSEY & CO., CARBON CAPTURE AND STORAGE: ASSESSING THE ECONOMICS 6 (2008), *available at* http://www.mckinsey.com/clientservice/ccsi/pdf/CCS_Assessing_the_Economics.pdf. This places them considerably far above many other emissions abatement and reduction strategies. *See* MCKINSEY & CO., PATHWAYS TO A LOW-CARBON ECONOMY 27 ex. 3.0.1 (2009) (showing that carbon capture and storage strategies such as "Coal CCS new build," "Iron and steel CCS new build," "Coal CCS retrofit," and "Gas plant CCS retrofit" have higher marginal abatement costs than other strategies). A more favorable report concludes that the cost of capturing, transporting, and storing carbon is closer to $30 per ton of CO_2. MASS. INST. TECH., THE FUTURE OF COAL, at xi (2007), *available at* http://web mit.edu/coal/The_Future_of_Coal.pdf. However, other studies suggest that the current estimates are still too low. *See, e.g.*, Mohammed Al-Juaied & Adam Whitmore, *Realistic Costs of Carbon Capture* 17 (John F. Kennedy Sch. of Govt., Discussion Paper No. 2009-08, 2009) (estimating $100–50 per ton). The McKinsey "Pathways" report also indicates that "2nd generation biofuels" have a relatively high marginal abatement cost relative to other strategies. MCKINSEY & CO., PATHWAYS TO A LOW-CARBON ECONOMY, *supra*.

[75] Concentrated solar energy is a form of solar energy that uses mirrors to concentrate sunlight to generate heat to drive a turbine to generate electricity. *Concentrating Solar Power*, U.S. DEP'T OF ENERGY, http://www1.eere.energy.gov/solar/printable_versions/csp_program.html (last visited Nov. 18, 2010). Production costs have dipped to such surprisingly low levels—they could be as little as seven cents per kilowatt-hour—that concentrated solar power has become as cheap as or cheaper than the more conventional solar power from photovoltaics. *Southwest Concentrating Solar Power 1000-MW Initiative*, NAT'L RENEWABLE ENERGY LAB., http://www.nrel.gov/csp/1000mw_initiative html (last visited Nov. 18, 2010); *see also* Kevin Bullis, *Cheap, Superefficient Solar*, TECH. REV. (Nov. 9, 2006), http://www.technologyreview.com/energy/17774/page1/ (reporting that the technology could soon make solar power as cheap as electricity from the grid).

[76] "Adaptation" is a general term used to describe all forms of adjustment to a climate-changed world that societies undertake, both now and in the future. For example, building sea walls is a way of adapting to higher sea levels, and has been frequently discussed as a way of protecting New York City from sea level rises. *See, e.g.*, *Climate Change Initiatives*, PLANYC 2030, http://www.nyc.gov/html/planyc2030/html/plan/climate_citywide.shtml (last visited Nov. 18, 2010). For a general discussion of adaptation, see, HENSON, *supra* note 16, at 299.

for undertaking costly (and, in light of the free-riding problem, potentially useless) mitigation measures.[77] Along similar lines, "geo-engineering" measures to physically or chemically remove greenhouse gases from the Earth's atmosphere, *after* they have already been released, can be speculative and risky, but offer humankind the technologically appealing chance to undo past mistakes.[78] Both adaptation research and geo-engineering research are controversial, in that they have the potential to detract from the mitigation mission, and divert resources away from mitigation efforts, even undermining international negotiations. But frustration at the pace and general ineffectiveness of international negotiations has naturally spawned inquiries about alternative ways to address climate change. Both adaptation and geo-engineering also change the way that countries view damages. Both may, if effective and if the costs were even remotely ascertainable, serve as a "backstop" for climate damages, in much the same way that the cost of alternative energy sources place an upper bound on the amount of money that could reasonably be spent on reducing emissions from coal combustion. As will be shown later, both may also reduce the incentives for strategic behavior.

7. *Mitigation costs are minimized by coordinated early action.* Even apart from the free-riding problem, early mitigation by only one country is more costly because it loses opportunities to undertake early *coordinated* action to reduce emissions and prepare a capital stock for transition into a less greenhouse gas-intensive economy. There is no doubt that efforts to innovate to reduce emissions that are undertaken globally will be more effective than those undertaken by some smaller subset of countries. Research and development efforts funded and supported by more governments and staffed by engineers and

[77] A related argument has been made that mitigation and adaptation are strategies that compete for finite funds, and that some adaptation measures are potentially more cost-effective in saving lives. For a discussion of these arguments, see INTERGOVERNMENTAL PANEL ON CLIMATE CHANGE, CLIMATE CHANGE 2007: IMPACTS, ADAPTATION AND VULNERABILITY 754–56 (2007).

[78] "Geo-engineering" is a general term used to describe a wide variety of measures aimed at reducing the atmospheric concentration of greenhouse gases, post-combustion or post-release, sometimes by directly removing greenhouse gases from the atmosphere, or reducing the amount of solar radiation that reaches the Earth. For a general discussion of geo-engineering, see HENSON, *supra*, note 16, at 330–32, and discussion *infra* in text accompanying notes 126–127.

scientists from more countries stand a better chance of finding breakthroughs than those of a smaller group of countries. Some research and development efforts might benefit from economies of scale in research and development. For example, carbon capture and storage technology is not, at this time, considered a very cost-effective emissions reduction measure.[79] However, research undertaken in which research costs are *shared* among several countries offers the potential to achieve some research and development economies of scale. Hence, the U.S., a country that generates about half of its electricity from coal-fired power plants,[80] has entered into joint carbon capture development and other research agreements with China,[81] another country heavily invested in coal combustion.[82] Further, coordination in mitigation efforts makes for larger and more competitive markets for mitigation technologies. A recent global glut in the supply of solar photovoltaic panels is not exactly a success story,[83] but it highlights the global nature of demand for solar photovoltaic panels. This global market has only been made possible with some joint action among a number of countries, including China, in promoting the installation of solar photovoltaic panels. These and other gains from coordination produce reductions in mitigation costs. Conversely, a lack of coordination is more costly.

8. *International climate negotiations and mitigation actions take place over many time periods.* Finite and infinite repeated games are nothing new to game theory, but the complexity of strategic interactions inherent in international climate negotiations poses tractability challenges for the modeler. Casual models of

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[79] *See* MCKINSEY & CO., PATHWAYS TO A LOW-CARBON ECONOMY, *supra* note 74.

[80] U.S. ENERGY INFO. ADMIN., ELECTRIC POWER MONTHLY NOVEMBER 2010, at 15 tbl.1.1 (2010), *available at* http://www.eia.doe.gov/cneaf/electricity/epm/epm_sum html.

[81] Press Release, U.S. Dep't of Energy, U.S.-China Clean Energy Announcements (Nov. 17, 2009), *available at* http://www.energy.gov/news2009/8292 htm) (also announcing "partnerships" with China in developing other technologies and strategies).

[82] *China Overview/Data*, U.S. ENERGY INFO. ADMIN., http://www.eia.doe.gov/emeu/cabs/China/Coal.html (last visited Dec. 4, 2010) ("Coal makes up 71 percent of China's total primary energy consumption, and China is both the largest consumer and producer of coal in the world.").

[83] Therese Poletti, *Solar Industry Seeing a Big Glut*, MARKET WATCH (Aug. 13, 2009), http://www.marketwatch.com/story/solar-panel-glut-may-lead-to-more-price-implosion-2009-08-13.

climate negotiations are reduced to a simple, static prisoner's dilemma problem,[84] which captures the collective action problem but not the intertemporal effects of actions.[85] Most importantly in modeling climate negotiations, there is no acknowledgement inherent in the prisoner's dilemma that a cooperative outcome could be reached if parties are permitted to *signal* an intent to cooperate to each other. Serendipitously, the nature of the global climate change problem is such that a communication of that sort, which could consist of a costly commitment to reduce emissions, could also have the effect of lowering future mitigation costs for everybody. An early mitigation measure would thus serve the dual purpose of lowering future mitigation costs, and transmitting a signal about intent to mitigate in the future. Above all, this early-stage action of commitment is what is most effective in recruiting participation into multilateral or bilateral negotiations.

9. *International climate change negotiations defy traditional game-theoretic labels.* The complexity of international climate negotiations is such that it is difficult to characterize using labels traditionally relied upon by game theoreticians to determine model structure. While computational limitations in modeling usually constrain many-player games to static games, the complexity of climate change requires that it be modeled as a dynamic process.

Information asymmetries suggest that perhaps climate negotiations should be modeled as a dynamic game of incomplete information,[86] and perhaps that a signaling model be used to model relationships between potentially cooperating countries.[87] After all, it has been said often in the course of international climate negotiations that there is a tremendous amount of mutual mistrust among negotiating parties.[88] A mutual suspicion and pessimism as

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[84] *See, e.g.*, SANDLER, *supra* note 9, at 224.

[85] For an example of a model that does consider intertemporal effects, see Shi-Ling Hsu, *What IS a Tragedy of the Commons? Overfishing and the Campaign Spending Problem*, 69 ALB. L. REV. 75 (2005) (modeling the tragedy of the commons as an extensive-form game).

[86] A leading treatise on applied game theory is by Robert Gibbons. ROBERT GIBBONS, GAME THEORY FOR APPLIED ECONOMISTS 173–232 (1992) (discussing dynamic games of incomplete information).

[87] For a description of signaling models, see *id.* at 183–209.

[88] Peter Baker, *Poorer Nations Reject a Target on Emission Cut*, N.Y. TIMES, July 9, 2009, at A1 (""They're saying, 'We just don't trust you guys,'" said Alden Meyer, of the Union of Concerned Scientists. "It's the same gridlock we had last year when Bush was president."").

to the ability of the other to navigate its respective domestic political landscapes to enact meaningful greenhouse gas emissions regulation is one source of mistrust. If that were the animating feature of climate negotiations, then a signaling model might be appropriate. In such a model, countries would have the opportunity to signal to each other that they are of a particular type—the mitigating type—and this would reassure other countries that early mitigation would be met with reciprocal mitigation, not free-riding. However, models of information asymmetry require substantial simplification of payoff structures, such that the costs and benefits of strategic climate choices cannot be adequately represented in a pure signaling game. This Article takes the approach of firstly modeling negotiations as a process with perfect information, and then relaxing that assumption to see what effect signaling has on the potential outcomes. This is done in Part V.A.1.

III. A PROPOSED MODEL

This Article proposes to begin with a simple model. The model is a two-player, three-period game of perfect information: two periods in which the players elect to undertake or not undertake mitigation measures to reduce greenhouse gases, and a third in which the countries will suffer damages from climate change if mitigation efforts in the first two periods are unsuccessful. The players move simultaneously in period one and again in period two, and the costs of mitigation in period two depend upon how much mitigation is undertaken in period one.

The proposed model begins with the assumption of perfect information. This is not a realistic assumption; as far as public policy and international relations is concerned, the problem of climate change is host to an unprecedented collection of uncertainties—scientific uncertainties about the effects of climate change and the timelines of those effects, uncertainty with respect to damages from climate change, uncertainty over how nations will react to climate change, uncertainty over the internal political dynamics of climate change in every country, and a host of other unknowns. However, attempting to incorporate these uncertainties at the outset of a modeling exercise is bound to end in failure. The approach taken in this Article is to begin with an assumption of perfect information, and to relax that assumption so as to see how outcomes change. This approach loses some resolution, and loses the ability to model interrelationships among some uncertainties, but still offers the possibility of some qualitative analysis. With the heated (for academics) debate among Stern and Nordhaus and others over just one parameter—the discount rate—seeming to play itself without resolution, it seems unproductive to attempt to nail down precise relationships in quantitative terms. The raw state of climate policy would benefit from a simpler analysis.

A. *The Parties*

The two players in this model are labeled as the U.S. and China. There are several reasons for this. First, they are the two largest greenhouse gas-emitting countries, together representing over 40 percent of the world's current annual carbon dioxide emissions.[89] Both of these two countries are absolutely essential to a meaningful attempt to curb emissions. Both countries have expressed a fear of jeopardizing economic growth and risking the loss of economic and industrial competitiveness that would supposedly accompany greenhouse gas reduction efforts.[90] They are two countries that are central to the debate over what to do about climate change.

Second, the U.S. and China aptly represent the divide between the developed world and the developing world in their greenhouse gas emissions profile, their economic ambitions, and their ideas on

[89] In 2008, the entire world emitted a total of 29,381 megatons of carbon dioxide. China emitted 6,550 megatons of carbon dioxide, and the U.S. emitted 5,595.92 megatons, accounting for a total of 41.3 percent. INT'L ENERGY AGENCY, 2010 KEY WORLD ENERGY STATISTICS 48, 56 (2010), *available at* http://www.iea.org/textbase/nppdf/free/2010/key_stats_2010.pdf.

[90] *See, e.g.*, *GOP: US Should Reject Climate Pact*, SEATTLE TIMES, Dec. 12, 2009, http://seattletimes.nwsource.com/html/politics/2010488118_apclimaterepublicans html; PEOPLE'S REP. OF CHINA, NAT'L DEV. & REFORM COMM'N, CHINA'S NATIONAL CLIMATE CHANGE PROGRAMME 19 (2007), *available at* http://www.ccchina.gov.cn/WebSite/CCChina/UpFile/File188.pdf ("The development history and trend of various countries has revealed the obvious positive correlations between per capita CO_2 emissions, per capita commercial energy consumption and the economic development level. In other words, with current level of technology development, to reach the development level of the industrialized countries, it is inevitable that per capita energy consumption and CO_2 emissions will reach a fairly high level. In the development history of human beings, there is no precedent where a high per capita GDP is achieved with low per capita energy consumption."); *cf.* Jonathan B. Wiener, *Climate Change Policy and Policy Change in China*, 55 UCLA L. REV. 1805, 1817 n.38 (2008) (describing China's focus on resolving tensions between economic growth and factors such as pollution).

wealth redistribution. The U.S., like most developed countries, is primarily interested in obtaining universal agreement on country-specific limits on greenhouse gas emissions and setting them to some historical baseline;[91] China, like most developing countries, is interested in linking greenhouse gas reduction with global wealth redistribution, setting emissions rights on a per capita basis, and/or linking responsibilities with historical emissions.[92] So, as the two players in this game, the U.S. and China serve as proxies for developed and developing countries, the two most important groups of interests that have clashed in the international climate context.

Finally, the U.S. and China have, in fact, at times held discussions as if they were the only two countries that needed to reach agreement on greenhouse gas emissions reductions. Certainly, they are the most important two, and an argument can be made that the U.S. and China could make a bilateral arrangement and then use their combined economic, political, and

[91] The U.S. proposal at the Copenhagen meetings was to reduce its emissions by 2020 to 17 percent below its 2005 levels, highlighting a dispute with Europeans that have insisted on maintaining 1990 as the baseline year as the Kyoto Protocol has done. *See* Press Release, The White House, President to Attend Copenhagen Climate Talks: Administration Announces U.S. Emission Target for Copenhagen (Nov. 25, 2009), *available at* http://www.whitehouse.gov/the-press-office/president-attend-copenhagen-climate-talks (discussing the U.S. proposal to reduce emissions in 2020 to 17 percent below 2005 levels). For a discussion of how the U.S. proposal conflicts with the European Union proposal, see Malcolm Dowden, Posting to LexisNexis Communities Environmental Law and Climate Change Community (Nov. 30, 2009, 3:19 PM), http://www.lexisnexis.com/community/environmental-climatechangelaw/blogs/topstories/archive/2009/11/30/copenhagen_3a00_-the-_1820_base-year_1920_-debate.aspx; *see also* Todd Stern, Special Envoy for Climate Change, Press Briefing at the United States Mission (Dec. 15, 2009) (transcript available at http://geneva.usmission.gov/2009/12/15/climate-change-dec15/).

[92] PEOPLE'S REP. OF CHINA, NAT'L DEV. & REFORM COMM'N, *supra* note 90, at 2 ("As noted by the *United Nations Framework Convention on Climate Change* (hereinafter referred to as UNFCCC), the largest share of historical and current global emissions of greenhouse gases has originated from developed countries, while per capita emissions in developing countries are still relatively low and the share of global emissions originating from developing countries will grow to meet their social and development needs. The UNFCCC stipulates clearly that the Parties to the Convention shall protect the climate system for the benefit of present and future generations of humankind, on the basis of equity and in accordance with their common but differentiated responsibilities and respective capabilities, and accordingly, the developed country Parties shall take the lead in combating climate change and the adverse effects thereof.").

military clout to coerce the rest of the world into falling in line. Such a bilateral-first approach would at least have the advantage of avoiding the cumbersome (and heretofore ineffective) multinational process implicit in the UNFCCC. At least, a cooperative outcome between the U.S. and China would be an important first step towards achieving multilateral agreement on emissions reductions. Agreement between the U.S. and China could be the foundation on which a multilateral agreement is built from the ground up.[93]

B. *Modeling Mitigation Costs and Damages*

This model is an attempt to simulate the consequences of current and near-future actions based on projections of future costs and benefits. The model consists of three time periods.

- In the first period, the countries simultaneously decide whether to undertake **Early Mitigation**, or **"EM"**, to reduce greenhouse gases. Relating this to real-life policy (but not in the proposed model), EM corresponds to *current or near-term mitigation policies,* those undertaken within the next five years.
- In the second period, the countries simultaneously decide whether or not to undertake **Late Mitigation**, or **"LM"**, to reduce greenhouse gases. In the real-life world, LM corresponds to *longer-term mitigation policies,* those undertaken in ten to forty years.
- In the third period, countries will suffer very long-term damages from climate change if mitigation measures are unsuccessful. The very long-term corresponds to events taking place more than forty years from now.

This model builds in highly stylized numbers to represent *non-discounted* mitigation costs. For EM, mitigation costs in period one are assumed arbitrarily to be *1* for each country undertaking them. EM by just one country is assumed to be equally effective no matter which country undertakes it, and is assumed to benefit both countries.[94] *Non-discounted* mitigation costs in period two are again, for illustrative purposes, chosen

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[93] This idea has, as far as the author is aware, only been suggested in a novel by Matthew Glass. MATTHEW GLASS, ULTIMATUM 49–51 (2009).

[94] This is consistent with the model's treatment of free-riding discussed *infra* in Part IV(c).

somewhat arbitrarily to be multiples of period one mitigation costs:

a) *2* if both countries mitigated in period one,

b) *4* if only one country mitigated in period one, and

c) *6* if neither country mitigated in period one.

This mitigation cost structure is meant to reflect the modeling challenges discussed above that pertain to: (1) how early actions affect later mitigation costs and (2) how coordination of action affects mitigation costs. Consistent with economic projections, *non-discounted* LM costs are assumed to be lowest when both countries undertake EM, higher when only one country undertakes EM, and highest when neither country undertakes EM. Again, the intuition behind these assumptions is simple: the less that is done in the near term to reduce emissions and convert economies into lower-carbon economies, the more expensive it will be to do so in the long term. And, for the reasons discussed above, if *either* country fails to undertake EM, then LM costs will be greater, *for both countries.*

It is worth emphasizing again that these mitigation costs are represented by highly stylized numbers. I have assumed that mitigation costs can be modeled using the simplest set of numbers to highlight some non-obvious results. And again, it is worth emphasizing that discounting may change the payoffs, such that a) is not necessarily better than b), which is not necessarily better than c), which is not even necessarily better than a climate-changed world. Again, the objective of this modeling exercise is to produce a descriptive account of the strategic dynamics of international climate negotiations, not a normative case for early mitigation.

C. *Free-riding*

This model makes the critical assumption that *both countries* must undertake LM in order for the world to avoid climate change (without geo-engineering). If either country fails to undertake LM, all mitigation measures in either period will have been futile, and both countries will have to absorb the full costs of a climate-changed world. This strong assumption is derived from warnings from the Stern Review that, as discussed above, countries are unlikely to be able to successfully mitigate the effects of climate change alone.[95] In essence, this model assumes that as between the two players, *any* free-riding in the second (LM) period would defeat efforts to avoid climate change.

Game-theoretic models to date illustrate the powerful effect of free-riding. William Nordhaus's RICE model (Regional Integrated Model of Climate and the Economy)[96] and the WITCH model (World Induced Technical Change Hybrid model),[97] the two main economic game-theoretic models of climate negotiations, both conclude that free-riding is of central importance. In the WITCH model, free-riding plays an almost determinative role in whether countries can successfully cooperate to achieve an optimal mitigation path. Bosetti et al. find that in cases of substantial non-participation, leading to substantial leakage of fossil fuel combustion, the costs of mitigation for those countries mitigating become astronomically high—as much as $2000 per ton of CO_2.[98] This price is a reflection of the difficulty faced by a mitigating country trying not only to curb its own emissions, but also to compensate for the fact that other non-mitigating countries are busily undoing all of the emissions reductions achieved by mitigation.

Both the Nordhaus and WITCH models involve large numbers of players—twelve "regions" of the world each comprising countries with similar economic and emissions profiles—such that cooperation is extremely difficult to achieve. And because both of these models assume that there can be no incentives to join a cooperating coalition of regions (such as trade sanctions against non-joiners), the only incentives to cooperate consist of the slightly better chance of avoiding climate change, an increment that is minimized by free-riding. Moreover, the WITCH model assumes that free-riding behavior would be *non-orthogonal* to mitigation measures; because mitigation measures are likely to reduce the global price of fossil fuels, the model builds in an assumption that the greater the mitigation, the greater the free-riding.[99] It should surprise no one that the prospects of cooperation to avoid climate change are bleak under these models.

95 *See* STERN REVIEW, *supra* note 1, at 450–65.
96 Nordhaus & Yang, *supra*, note 10.
97 *See supra* note 52.
98 Bosetti et al., *supra* note 52, at 27.
99 *Id.* at 9–14.

The simplifying assumption in the model proposed in this article that free-riding would absolutely preclude cooperation and avoidance of climate change is meant to make free-riding exogenous and sidestep modeling it. This is not to deny that as a descriptive matter, free-riding is endogenous and increases with mitigation efforts. But the purpose of this model is to isolate certain factors that might advance cooperation, even in the face of potential free-riding.

A second reason for exogenizing the free-riding problem is that no matter how daunting the problem, each country must still make decisions on greenhouse gas mitigation that serve its own population, and to some extent exogenize considerations of what other countries are doing. To repeat for emphasis a condition stated above, in order for there to be cooperation, every country will have to accept that their cooperation is a *necessary, but not sufficient, condition* to avoiding the most severe climate change effects. Given sufficient exigency, countries must make that probabilistic determination without the luxury of resenting the possibility that others will defect; given the stakes, countries must eventually put aside questions of fairness and make a decision that maximizes their own welfare, even if it results in the unjust enrichment of others.

D. *Discounting*

Future payoffs are discounted in this model. Each country has a specific discount rate. A number of considerations are packed into the discount rate in this model. In addition to the purely economic sense in which a discount rate operates, this model assumes that a country-specific discount rate also embodies a preference for delay because of the possibility of technological learning that reduces future mitigation costs, as well as future adaptation costs. WITCH and other integrated assessment models separate out technological learning as a factor that affects the timing of mitigation decisions. This model wraps technological learning into the discount rate, as in rough terms, the effect would be the same: to make delayed action more economically attractive than near-term action.

As noted above, modeling political actors such as climate negotiators requires the utilization of not just a traditional economic discount rate, but a *political* one—the rate at which decisionmakers discount future costs and benefits while making present decisions. Apart from the purely economic reasons to discount, it would be naïve to think that climate negotiators would weight the welfare of future citizens of their country as highly as they weight those of their current constituents. In fact, it seems adventurous to assume that political actors with electoral pressures make decisions that are as generous to future generations as an economic discount rate would have it. In other words, a discount rate used to model political decisions by governments would, as a descriptive matter, probably be higher than a purely economic one.

This model assumes a country-specific discount rate only over the three time periods in the model, and not, like the WITCH model or other integrated assessment models, over fifty to one hundred years and in small increments. Second period mitigation costs are discounted at its country-specific rate, and third period damages are doubly discounted. The discount rate in this model is thus not meant to represent a discount rate that is expressed in annual terms, as discount rates often are. In the model, discounting is expressed as discount *factors*, such that a discount factor x is expressed as $(1\text{-}r)^n$ where r is the discount rate and n is the number of years. For simplicity, the three periods are assumed to be spaced evenly apart, so that n is assumed the same between periods one and two as it is between periods two and three. r is assumed to be constant. Discounting payoffs in period two is thus accomplished by multiplying by x; discounting payoffs in period three is accomplished by multiplying by x^2.

E. *Damages from Climate Change*

In this model, damages from climate change are depicted as A for the U.S. and B for China. Each country *perceives* its own damages, and that these perceived costs could change over time, as they seem to have in recent years in both the U.S. and China. Country-specific damages from climate change are of course highly uncertain. And obviously, it is not just the very long term in which many projected climate change impacts will be manifest.[100] But the most serious impacts occur in this long time

[100] An extensive federal interagency review of the impacts of climate change has concluded that the impacts of global climate change are already being felt in the U.S. U.S. GLOBAL CHANGE RESEARCH PROGRAM, GLOBAL CLIMATE CHANGE IMPACTS IN THE UNITED STATES 9 (2009), *available at* http://downloads.globalchange.gov/usimpacts/pdfs/climate-impacts-report.pdf.

frame, and this model best captures the nature of the intertemporal tradeoffs by separating out time periods for mitigation, which occur in periods one and two, and for damages, which occur in period three.

The simplest conception of climate change damages imagines them as those costs that are incurred as a direct or indirect result of the effects of climate change. They may include, for example, rescue and relief efforts incurred from more severe tropical storms (over and above those that would have occurred anyway), damages to the agricultural sector from regional shortages of water due to climate change, and damages to cities that find themselves, in a climate-changed world, below sea level. More ambitious conceptions of climate change should take into account the likelihood that positive feedback effects may amplify and/or accelerate the effects of climate change.[101] The possibility that the dangers of climate change have been underestimated because the small climate changes already caused will beget other greenhouse gas releases, and further climate change, is alarming but as of yet hard to evaluate. Should *A* or *B* (U.S. and China damages, respectively) include the expected value of the possibility of positive feedback and catastrophic effects? They might well not, given the very uncertain projections surrounding the possibility of catastrophic effects. But Weitzman's warning about the cost-benefit analyses that either ignore or falsely purport to account for catastrophic outcomes suggests substantial caution is warranted.[102] Obviously, a huge range of potential effects are possible, and there are no doubt a number of currently unforeseen effects that would add to the costs. For now, a simple model is proposed and a set of unique solutions derived.

F. *Finally, the Model*

Given the modeling assumptions described above, the model, a game of perfect information, is set out in extensive form in Figure 1 below. The players move simultaneously in period one and in period two. The payoffs of the U.S. and China are derived from the sum of the mitigation costs (set out in Part IV.B. above) and damages from climate change, if it occurs. These are observed in period one, so period two payoffs are discounted (multiplied by

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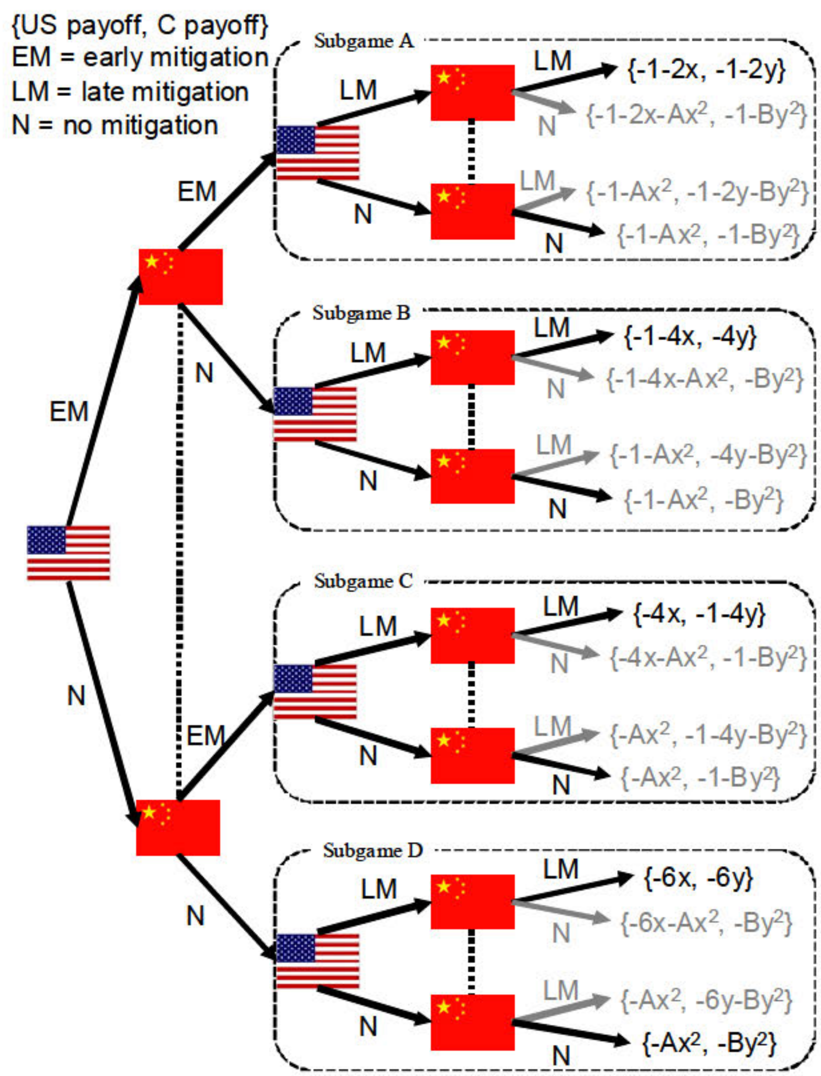
[101] *See generally* Torn & Harte, *supra* note 13.

[102] *See supra* note 6 and accompanying text.

x) and period three payoffs are doubly discounted (multiplied by x^2).

Figure 1
Early/late/no mitigation game



While this model appears complicated in extensive form, it is useful to notice two things: first, period two of the game consists of four discrete subgames (denoted by A through D in Figure 1), corresponding to different permutations of whether the countries undertake EM or not. Second, subgames A, B, and C have only one stable Nash equilibrium,[103] and subgame D has two, so that there are only five possible outcomes:

1. Both U.S. and China do EM and both do LM.
2. U.S. does EM, but China does not, then both do LM.
3. China does EM, but U.S. does not, then both do LM.
4. Neither U.S. nor China does EM, but both do LM.
5. Neither U.S. nor China does EM or LM, and climate change occurs.

This winnowing-down of outcomes is possible because first, no Nash equilibrium could involve just one party doing LM. Under perfect information, each player would know in advance whether the other was going to do LM. Since both players must do LM in order to prevent climate change, there is no point in one country undertaking LM if it knows the other will not. Second, *either player* doing EM implies a cooperative Nash equilibrium, because under perfect information the parties would *know in advance* whether cooperation was possible; if it was impossible, then neither party would bother with EM. Hence, subgames A, B, and C, in which at least one player undertakes EM, have a unique cooperative Nash equilibrium, and subgame D in which neither player undertakes EM has two possible Nash equilibria: a cooperative Nash equilibrium and a non-cooperative outcome resulting in climate change.

It is illustrative to consider subgame D and observe the conditions under which doing EM would appear to be inefficient and also when non-cooperation (and suffering damages from climate change) is efficient. First, consider the possibility that both the U.S. and China would prefer to avoid climate change damages (perceive a very high *A* and *B*, respectively), but both have a high enough discount rate that they prefer only LM (have a low *x* and *y* respectively). Taking a look at the payoffs for the U.S. (the Chinese analysis would obviously be identical), this would mean that the U.S. prefers the payoff of outcome 4 to outcome 2 and outcome 5 (outcomes 1 and 3 are not possible because China

[103] In its simplest form, a Nash equilibrium is an outcome whereby each player in a game pursues a strategy that is the best strategy given every other player's best strategy. It is an equilibrium, because there is no incentive for any player to deviate from his strategy. GIBBONS, *supra* note 86, at 8.

will not do EM):

$-6x > -1-4x$ and $-6x > -Ax^2$

or, in other words:

$x < ½$ and $Ax > 6$[104]

So if $Ax > 6$ and $By > 6$, but also $x < 1/4$ and $y < 1/4$, and if both countries believe these conditions to hold, then a cooperative Nash equilibrium would be one in which both the U.S. and China eschew EM, but both do LM—the result of both countries being sufficiently concerned about the damages of climate change, but also both countries having high discount rates.

The differences between outcomes 1 through 4, all of which end in cooperation, also illustrate one important role of the two-stage mitigation process. Why not combine EM and LM? Separating out EM from LM in two separate periods is important for a number of reasons, but foremost among them is the illustration of how different parameters for different countries may alter the allocation of the burden of mitigation across countries or across time. Also, the most interesting results from the model are derived when the perfect information assumption is relaxed (Part IV.A), and period one actions and inactions explicitly affect the decision environment for period two.

A unique solution thus exists for each set of values of *A*, *B*, *x* and *y*.[105] Conceptually, cooperative Nash equilibria occur for higher values of *Ax* or *By* or both, and higher values of discount factors *x* and *y* or both. The outcomes of this simple game are mapped in Figure 2. The conditions are formally derived in Appendix A. Boundary conditions are omitted, so only inequalities are analyzed. It seems sufficient for illustrative purposes to assume that cooperative Nash equilibria are unstable unless the conditions are strictly satisfied.

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[104] Again, the *6* is just an arbitrarily chosen mitigation cost for LM with neither party doing EM. To put numbers to this exercise, if $x=1/6$, then $-6x = -1$. Recall that the payoff of the U.S. doing both LM *and* EM (assuming that China also does EM and LM) is $-1-2x$, so the U.S. payoff is $-1-2/6 = -4/3$. Recall that the payoff of U.S. doing LM but not EM (assuming that China does the same) is $-6x$, so the U.S. payoff is -1. Assuming China does the same as the U.S., the U.S. has a higher payoff only doing LM.

[105] An exception to this exists in the form of an unstable cooperative Nash equilibrium. The exception involves low discount factors (high discount rates), and illustrates a classic prisoners' dilemma in that a socially optimal cooperation is foiled by individually optimal self-interest. This is derived in Appendix A.

Figure 2
Outcomes of Perfect Information Game

	Ax < 2	*2 < Ax < 4*	*4 < Ax < 6*	*6 < Ax*
By < 2	*No Cooperation*	*No Cooperation*	*No Cooperation*	*No Cooperation*
2 < By < 4	*No Cooperation*	*Cooperation only if x > ½ AND y > ½*	*Cooperation only if x > ½ AND y > ½*	*Cooperation only if x > ½ AND y > ½*
4 < By < 6	*No Cooperation*	*Cooperation only if x > ½ AND y > ½*	*Cooperation if x > ½ OR y > ½*	*Cooperation if x > ½ OR y > ½*
6 < By	*No Cooperation*	*Cooperation only if x > ½ AND y > ½*	*Cooperation if x > ½ OR y > ½*	*Cooperation*

This game thus boils down to two key factors in the determination of whether a country would be inclined to mitigate to avoid climate change: the country's climate change damages and its discount rate. But whereas the damages only affect the likelihood that a country will be inclined to mitigate, the discount rate affects both the inclination to mitigate as well as the timing of mitigation.

By focusing in on these two parameters, the analysis of international climate negotiations becomes simpler, if still somewhat crude. Most strategic interactions can be linked in some way to one of these parameters, or can be modeled as a change in these parameters. The goal of this article is not to quantify, as more complex models do, costs, benefits, and probabilities. The goal is to illustrate the effects of as many strategic considerations as possible by exploring how they affect these two parameters, and how they concomitantly affect the likelihood of reaching a cooperative Nash equilibrium.

IV. Modifying the Game-Theoretic Model

It is important to keep in mind the purpose of modeling behavior under an assumption of perfect information. It is not as if there is suspense in stage 2; the point of modeling is to illustrate how differences in parameter values—in this game the perceptions of damages and the discount rates—affect the distribution of costs and the sequence of moves by each player. The model under perfect information simply illustrates the relationships between pieces of information.

That said, if this article ended here, the reader would be justified in complaining that the proposed model explains little, especially given the somewhat arbitrary choices of mitigation costs. The model is useful, however, as a baseline for showing what happens to the probability of a cooperative outcome once the assumptions are relaxed. That is, what this model can illustrate about international climate negotiations can be gleaned by perturbing various aspects of the model and seeing what happens to the likelihood of a cooperative outcome. What follows is a series of modeling perturbations, with accompanying lessons about climate negotiations.

A. *Imperfect Information: Uncertainty and Strategic Behavior*

As acknowledged earlier, the greatest leap of this model is the assumption of perfect information. Much of the difficulty and shenanigans swirling about the climate change public policy problem can be traced to the fact that many pieces of information are uncertain—scientific, economic, and political. In the first part of this Part, the perfect information assumption is relaxed and the effect of uncertainty is explored. As well, uncertainty in all its forms gives rise to the possibility of strategic behavior, which is discussed in a second subpart to this Part.

Uncertainty negatively affects prospects for a cooperative outcome. The reason for this is that cooperation in this model is a joint product. Given that this model adopts a cost-benefit decision framework, and given that mitigating greenhouse gases is only rational if others mitigate, it is not only important to understand one's own costs and benefits, it is vitally important to understand the costs and benefits of other countries. If one country perceives that *another* country's cost-benefit analysis would disfavor mitigation, then it would have reason to believe that cooperation is doomed; under those circumstances, it would be irrational to mitigate. Uncertainty can have a devastating effect on the prospects for cooperation.

1. *Uncertainty*

There are a variety of ways that uncertainty can wreak havoc in climate policymaking and international relations. For example, scientific uncertainty inherent in climate change seems to have produced psychological responses that challenge assumptions of rationality. Psychologists and enlightened economists have long understood that people make poor decisions under uncertainty. When faced with the task of weighing certain information against uncertain information, people systemically overweigh the certain information.[106] Thus, when faced with a choice of *certain* mitigation costs and *uncertain* damages from climate change, humans will be inclined to bias towards the former. In a sense, the manipulation of public opinion by those opposed to climate change is merely a scaling-up of a human propensity to make, on an individual level, mistakes in judgment that involve uncertain information. In the context of this game, which naively assumes a simple cost-benefit calculation, scientific uncertainty clearly biases decisions against mitigation, and towards delay. These uncertainties also exacerbate the collective action problems of negotiating climate agreements.[107]

Uncertainty also raises the possibility that parties could *signal* future intentions to each other, since imperfect information renders future actions probabilistic. The mitigation cost structures assumed by the model under perfect information already build in a considerable amount of information about potential future paths. The fact that LM costs more, the less EM is undertaken, means that failure by either player or both players to undertake EM creates a world in which a cooperative outcome can occur in a *narrower* set of possible combinations of values of A, B, x, and y. This does, in fact, reflect what most economists will say about

[106] *See* Daniel Kahneman & Amos Tversky, *Prospect Theory: An Analysis of Decisions Under Risk*, 47 ECONOMETRICA 263, 263 (1979); *see also* Amos Tversky & Daniel Kahneman, *Judgment Under Uncertainty: Heuristics and Biases*, 185 SCIENCE 1124 (1974) (discussing the effects of various heuristics when making judgments in the face of uncertainty).

[107] *See* SANDLER, *supra* note 9, at 224.

EM: a little bit now could save a lot later; so much so that doing nothing now forecloses a number of future options.[108]

But even apart from the hard path-dependencies created as part of the structure of the game, undertaking EM must also, in the real world of international relations, mean something else: it must signal a turn, political or social, representing a commitment to some different path. EM in this real world, then, has more than just an economic consequence for the future; it has the effect of irrevocably committing some resources to mitigating greenhouse gas emissions, and signaling the possibility of reciprocity should another party make a similar or greater commitment. Of course, political decisions can be undone and social movements can reverse themselves. But the nature of a costly and necessarily long-term commitment to reduce greenhouse gas emissions means that there will be political costs should a future administration renege on these commitments.[109] This is important information to other interested countries.

For example, consider China's rapid deployment of coal-fired power plants.[110] Because it is so costly to retire these plants, this current emphasis on coal-fired electricity production has very significant long-term implications. The U.S. could be forgiven for doubting that China would undertake any future mitigation in the form of reducing electricity-related greenhouse gas emissions. There are, of course, a number of other things that China could do twenty to forty years from now that might amount to late mitigation, but it is hard to avoid interpreting such a breakneck pace of construction of coal-fired power plants as a prioritization of economic development over climate concerns.

As for the United States, consider the wavering prospects of climate law—federal and state legislation, as well as the occasional dramatic development in climate litigation—and consider how these twists and turns affect the decision environments of any country considering greenhouse gas mitigation. Supporters have

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[108] *See supra* notes 67–71 and accompanying text.

[109] For an economic game-theoretic model of the costs of breaking commitments to reduce greenhouse gases, and how these affect international negotiations, *see* Ana Espinola-Arredondo, *Free-Riding and Cooperation in Environmental Games*, 11 J. PUBL. ECON. THEORY 119 (2009).

[110] As of 2007, China was adding coal-fired power plants capacity *each year* that was comparable to the entire grid supply of the United Kingdom. MASS. INST. TECH., *supra* note 74, at ix.

emphasized what it would mean to the international community if the U.S. Congress passed anything that commits to greenhouse gas reductions. Of course, legislation and even case law can be undone by future administrations and courts. But every case and every piece of legislation creates its own expectations, and therefore creates its own stickiness. This would have been particularly true of the American Clean Energy and Security Act of 2009 (the Waxman-Markey Bill) that passed the House of Representatives, had it become law. In financing the political support needed to make an expensive transition to a lower-carbon economy, the authors of the bill have doled out considerable benefits to a variety of industries. After an unprecedented lobbying effort,[111] the bill's cap-and-trade program wound up including a stream of free emissions allowances worth an estimated $378 billion (in present value terms) to a Christmas list of powerful industries.[112] Many have been critical of the rents that have been distributed in closed-door negotiating sessions, as well as the bill's scaled-down ambitions.[113] It is worth keeping in mind, however, that if the bill ultimately became law, it would be difficult for the United States to retreat in the future, especially given the vested industry interests that would have been the beneficiary of Representatives Waxman and Markey's generosity. This would be an important signal to the rest of the world.

Under uncertainty, then, actions in period one play important dual Bayesian roles. First, they provide information about how a country perceives its damages from climate change and/or its discount rate (as conceived in this game). Second, the path dependencies created by political decisions to commit resources (and the social currents that underlie these decisions) to mitigating greenhouse gas emissions are such that there is at least *some* political and economic permanence attached to these course

[111] It was reported that 1,150 groups lobbied the U.S. Congress in just the twelve weeks leading up to passage of Waxman-Markey. Timothy Gardner, *Lobbyists Elbow for Influence on U.S. Climate Bill*, REUTERS.COM, Aug. 12, 2009, http://www.reuters.com/article/2009/08/12/us-climate-lobbying-idUSTRE57B61Y20090812.

[112] For one of many analyses of the Waxman-Markey bill and the political concessions that were made in order to obtain passage, see Hsu, *supra* note 35.

[113] *See, e.g.*, James Hansen, *G-8 Failure Reflects U.S. Failure on Climate Change*, HUFFINGTON POST (July 9, 2009, 10:33 AM), http://www.huffingtonpost.com/dr-james-hansen/g-8-failure-reflects-us-f_b_228597 html.

changes. Both of these types of information may, in a game-theoretic setting, affect the willingness of other countries to undertake LM.

There is a further significance and importance to uncertainty and signaling that is not easily captured by a game-theoretic model. The model in this article only involves two game-playing stages—an improvement over earlier static depictions—but what if there were many stages, with many pieces of information being generated at each stage? This is in reality what is happening on the world stage, as administrations change, as climate science develops, and as the discourse and information about climate change evolves.

The discouraging or encouraging effects of early behavior such as EM may have a positive feedback effect that amplifies the signaling that might be modeled in this game. Consider again, for example, if the United States interprets Chinese construction of coal-fired power plants in a very negative way: that China must view its risks from climate change to be quite manageable, and is therefore dubious about mitigating greenhouse gases. In a multi-stage game, a subsequent stage could involve some action (or reaction) by the United States that similarly could be interpreted by China as retreating from any commitments to mitigate greenhouse gas emissions—for example, political developments that signal a lower likelihood of passage of federal climate legislation. Given the volatile political relationship between the United States and China, this could be a very realistic signal from the United States that it, too, is inclined to take its chances with climate change, especially if Chinese reluctance to mitigate would render American action unilateral and therefore futile. What would *then* be a Chinese response? Seeing U.S. hostility and dimming prospects for a cooperative outcome on mitigating greenhouse gas emissions, it may decide that further retrenchment and further savings are in order. And so on. What a simple two-stage game fails to capture is the possibility of a dynamic unraveling of prospects for cooperation. Some action that could be perceived as a negative signal could provoke something that could reasonably be perceived as a negative reaction from the other, which would, because of the need for cooperation, induce further retreats. This dynamic has been on display often in international climate negotiations. Discussions on implementation of the Copenhagen Accord have faltered amid cross-accusations of a lack of commitment to climate policy; U.S. negotiators fault other countries for backtracking on commitments made in Copenhagen, while other countries point to the failure of the United States Senate to pass legislation for casting a pall over negotiations.[114]

Conversely, positive action on greenhouse gas mitigation could build on itself. In addition to its investment in coal-fired power plants, China has also invested heavily in renewable energy technologies, aiming to become a leader in technological development in these industries.[115] This action seems all the more credible as a signal in light of China's actions to insulate these nascent industries from international competition.[116] Besides being a strategic industrial threat, a U.S. interpretation could also view this as a Chinese expectation that energy generation in the future will be low-carbon. Even if this does not explicitly signal *current* Chinese willingness to reduce greenhouse gas emissions, its investment in a lower-carbon future is a sign that China anticipates such a future. That could be a signal of future Chinese acquiescence, since a lower-carbon future would be impossible without Chinese acceptance. That in turn could prompt American optimism, and perhaps usher along domestic greenhouse gas legislation that promotes U.S. renewable energy research, which would further signal to China a U.S. preparation for a lower-carbon future. And so on.

Uncertainty, and the signaling it necessitates, thus carries with it heightened consequences. In an environment of uncertainty with respect to the science, politics, and economics of climate change, even actions that would otherwise be viewed as inconsequential could play important informational roles. With so much at stake and so much uncertainty, the worldwide yearning for information would naturally lead to a situation in which a seemingly disproportionate amount of attention is paid to so many minor events. Uncertainty about climate change means that knowledge about climate change and knowledge about what different

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[114] Friedman, *supra* note 37.

[115] Lisa Friedman, *China Leads Major Countries with $34.6 Billion Invested in Clean Technology*, CLIMATEWIRE, Mar. 25, 2010, http://www.eenews net/features/documents/2010/03/25/document_cw_03.pdf (citing THE PEW CHARITABLE TRUSTS, WHO'S WINNING THE CLEAN ENERGY RACE? (2010)).

[116] Keith Bradsher, *Drawing Critics, China Seeks to Dominate in Renewable Energy*, N.Y. TIMES, July 14, 2009, at B1.

countries think about climate change is evolving. A multi-stage game illustrates the role of early actions as part of that evolution of climate information. One should not be surprised that in such a setting, little things could mean a lot.

2. *Strategic Behavior*

Perhaps even more troubling, scientific uncertainty allows posturing to take place within domestic and international debates over allocations of burden-sharing. Economic uncertainty invites highly interested parties to produce their own numbers with their own opaque assumptions, clouding an already confusing public discussion. Political uncertainties constrain or appear to constrain policymakers and negotiators.

The strategic behavior problem discussed in this part illustrates some of the pitfalls of the way that climate negotiations have been conducted thus far. In the international realm, a somewhat disingenuous discussion about the "justice" of the climate change problem has helped enable domestic and international posturing that has masked common interest and threatened the stability of international and domestic negotiations. There is certainly an appeal to the argument that developed countries that have benefitted from the combustion of fossil fuels (and therefore mostly created the problem of climate change) should assume a higher burden in reducing greenhouse gases. The fact that the Kyoto Protocol set out obligations for developed countries but not developing countries[117] might reflect this understanding. Most would probably also agree that developed countries should also make what amounts to *side payments* to developing countries to assist in their economic development in a lower-carbon future, and to assist in adaptation to the effects of climate change.[118] Were strategic behavior absent from this

[117] *See* Kyoto Protocol, *supra* note 20.

[118] As part of the recent Copenhagen climate negotiations, developed countries pledged to donate $100 billion per year by 2020 to begin assisting developing countries. United Nations Framework Convention on Climate Change, Conference of Parties, Fifteenth Session, Copenhagen, Dec. 7-18, 2009, ¶ 8, U.N. Doc. FCCC/CP/2009/11/Add.1 (Mar. 30, 2010). While the Clean Development Mechanism has come under intense criticism for its ineffectiveness, as noted *supra* in text accompanying note 42, the notion that development assistance is warranted has remained intact. Critics of the Clean Development Mechanism propose alternative means of financing, rather than abandonment of the idea of making side payments to developing countries. *See*,

process, there would be no overall welfare implications—side payments would merely be converting potential Pareto Superior moves into Pareto Superior moves. However, only heroic naïveté would entertain such a notion.

Strategic behavior as modeled in this article also pervades domestic negotiations in crafting domestic legislation. Regulating greenhouse gases and transitioning whole economies into a lower-carbon mode manifestly creates winners and losers. In both domestic and international climate negotiations, side payments will clearly be necessary and widespread in order to obtain sufficient agreement on mitigating greenhouse gases. This Article, however, will confine itself to the modeling of side payments in the international realm. In modeling the effects of strategic behavior and the resulting potential for mischief, this model provides a conceptual linkage between the justice discourse[119] and the consequentialist discourse[120] that have grappled for supremacy in the climate change debate.

This model introduces the possibility of side payments by allowing side payments to be made in period one, to induce EM

e.g., Wara & Victor, *supra* note 42, at 6. China has acted as a spokesnation for developing nations. For example, China emphasizes the principle that developed countries should take the lead in reducing greenhouse gas emissions. PEOPLE'S REP. OF CHINA, NAT'L DEV. & REFORM COMM'N, *supra* note 90, at 58 ("According to the principle of 'common but differentiated responsibilities' of the UNFCCC, the Parties included in Annex I to the Convention should take the lead in reducing greenhouse gas emissions. For developing countries with less historical emission and current low per capita emission, their priority is to achieve sustainable development."); *see also Copenhagen Climate Talks (UNFCCC)*, N.Y. TIMES, http://topics nytimes.com/top/reference/timestopics/subjects/u/united_nations_framework_convention_on_climate_change/index html (last visited Dec. 18, 2009) ("The Chinese continue to resist mandatory ceilings on their emissions. They argue that the developed countries have churned out greenhouse gases for decades and should bear a greater burden in reducing them. Developing nations, they add, should not be restrained in using economic development to raise their standards of living, even if greater emissions result.").

119 For one synthesis of the many, many works on climate justice, see Sonja Klinsky & Hadi Dowlatabadi, *Conceptualizations of Justice in Climate Policy*, 9 CLIMATE POL'Y 88 (2009). Domestically, the fairness within countries of certain policy measures has featured prominently in the instrument choice literature. For one of several economic analyses of the distributional impacts of different greenhouse gas regulatory instruments, see Dallas Burtraw, Richard Sweeney & Margaret Walls, The Incidence of U.S. Climate Policy (Sept. 17, 2009) (unpublished manuscript), *available at* http://www.rff.org/documents/RFF-DP-09-17.pdf.

120 *See, e.g.*, BARRETT, *supra* note 10; STEWART & WIENER, *supra* note 23; Wiener, *supra* note 90.

and LM, or period two to induce LM only. The simpler case is a side payment in period two to induce the other party to undertake LM. Consider, for example, the following possible scenario: the U.S. perceives its damages from climate change to be very high, and is willing to undertake LM, but China perceives its damages to be low enough that it is only willing to undertake LM in certain period two subgames. Suppose that

$Ax > 6$ and $x > 1/2$ *and*

$2 < By < 4$ and $y < 1/2$

Given these assumption, the players will enter period 2 in subgame B (if $x < 1/2$, the parties would enter subgame D, and the analysis would be similar). In subgame B, the parties would both undertake LM (and a cooperative Nash equilibrium is reached) if both the U.S. and China have higher payoffs from LM than from facing climate change, i.e. if both of the following are true:

$-1-4x > -1-Ax^2$ and $-4y > -By^2$

which reduces to the pair of conditions

$Ax > 4$ and **(1a)**

$By > 4$ **(1b)**

But we have assumed that $By > 4$, so we know that subgame B would ordinarily end with no cooperation. However, the U.S. can make a side payment in the amount of ***s*** to China so that LM becomes worth it. Adding a side payment ***s*** into a comparison of payoffs in subgame B for the U.S. and China yields

$-1-4x-s > -1-Ax^2$ and $-4y+s > -By^2$

which (dividing through by $-x$ and $-y$) means that

$Ax > 4 + \frac{s}{x}$ and **(2a)**

$By > 4 - \frac{s}{y}$ **(2b)**

What this side payment has done is substitute conditions 2a and 2b for conditions 1a and 1b, adding in the ***s/x*** and ***s/y*** terms to create new conditions for a cooperative Nash equilibrium in subgame B. If the side payment is conditioned upon China's undertaking LM, conditions 2a and 2b represent the new test for whether cooperation will occur. So if there is an ***s*** such that, starting from the initial assumptions, conditions 2a and 2b can be satisfied, then a side payment from the U.S. to China could rescue what would otherwise be a doomed effort to cooperate to mitigate greenhouse gas emissions. The same analysis would apply if the parties found themselves in subgame D, only the conditions would be more stringent.[121]

A side payment could also be made in period one. In order for a side payment to work in period one, however, two conditions need to be satisfied, not just one. Not only must a side payment be possible to induce LM by both parties, but the side payment must induce the parties to enter a subgame in which LM is induced for both parties. This slightly more complicated derivation is set out in Appendix B. As long as there is perfect information regarding all of the parameters, there is no reason that a side payment could not convert all potentially Pareto-efficient situations into Pareto-efficient outcomes.

The trouble arises, of course, as it does in simple Coasean bargaining situations, when there is imperfect information. Damages or a country's perception of its own damages may be uncertain, as well as discount rates or a country's perception of its own discount rates. If, for example, the U.S. is not certain of *B* or *y* (China's climate change damages or its discount rate, respectively), then failure by China to EM could be interpreted as one of four possible things: (1) a signal that China believes its climate change damages to be low; (2) a signal that China has a high discount rate; (3) both (1) and (2); or (4) strategic behavior in the form of a *false* signal in order to extract a period two side payment. The trick for the country that wants to avoid climate change (in this scenario, the U.S.) is to ascertain the real reason why China eschews EM, and whether it would later undertake LM. For the country that eschews EM (in this scenario China), it may stand to gain a benefit in the form of a side payment, even if it intended to undertake LM after all.

If China does undertake strategic behavior, however, it runs a risk: instead of extracting a side payment from the U.S. in period 2, China's failure to undertake EM in period 1 could cause the U.S. to abandon hope of cooperation and simply refuse to undertake LM in period 2. A number of misunderstandings could lead to strategic behavior backfiring: China could overestimate *A*

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[121] The side payment would have to be made so that both the conditions $Ax > 6 + \frac{s}{x}$ and $By > 6 - \frac{s}{y}$ would be satisfied.

and x, so that it expects a side payment from the U.S., when in fact none would be forthcoming; the U.S. could underestimate B and y, such that it does not believe it could afford a large enough side payment to induce China to LM, when in fact it could; the values and understandings of all of the parameters could change over time, and failure to EM could have foreclosed options. Because EM makes LM cheaper, strategic behavior that involves not doing EM could put the parties into a subgame in which LM is too expensive, while it might not have been too expensive in a different subgame.

For example, it could also be the case that China assumes that:

$Ax > 4$ and China knows that for itself $By > 4$,

but that it thinks it can finagle a side payment from the U.S.. But suppose, in reality:

$4 > Ax > 2$,

and if the U.S. undertook EM and China did not, then the parties would be in subgame B, and the U.S. would not, as it would have in subgame A, have undertaken LM. In subgame B, Ax would have to be greater than 4 in order for it to be worthwhile, but in subgame A it would only have to have been greater than 2 to have been worthwhile. So by trying to extract a side payment out of the U.S., China would have created an unnecessarily stringent condition for cooperation, and induced an outcome that would be inferior to the one that would have occurred if China had not tried to deceive the U.S.

Whether China and developing nations are truly sincere about their demands for side payments is obviously hard to know, perhaps even for the Chinese and the developing nations themselves. It could well be true that developing countries truly view their climate-change damages as low, given that many of them start from a current position of poverty, and climate-related damages would not pose a *huge* loss of wealth as it might for wealthy countries. For the most part, international institutions and climate negotiations have acknowledged this dynamic, although the degree to which efforts have met the needs of developing countries is a subject of intense disagreement. The Clean Development Mechanism of the Kyoto Protocol, which provides for the issuance of emissions credits for developed countries towards meeting their Kyoto targets if they fund an emission-reducing project in a developing country, was intended to transfer wealth to developing countries. Its success at reducing greenhouse gases and aiding those most in need, however, has been called into question.[122]

The Copenhagen negotiations have picked up where previous negotiations have left off. In the opinion of U.S. climate negotiator Jonathan Pershing, a number of countries viewed the Copenhagen summit not as a forum for climate change solutions, but as a process for wealth redistribution.[123] In this regard, Copenhagen can not be considered a complete failure from these countries' perspectives: the U.S. announced a commitment at Copenhagen to help raise $100 billion to assist developed countries with adapting to climate change.[124]

Given this kind of uncertainty and a demonstrated propensity to seek side payments, it becomes understandable why a country might seek to delay mitigation. Uncertainty may explain some current hesitation among developed countries to undertake mitigation, as well as what in this game would be considered EM. Uncertainty and the potential for mischief through strategic behavior can be reduced by waiting until period two. It is true that failing to undertake EM forecloses options, but looking at climate negotiations as not just a two-stage game, but a more realistic multi-stage game might soften the stark finality of certain decisions. A country looking at a series of annual decisions over many years might well trade the loss of options for some better information. In a world where there are multiple opportunities to undertake EM, the refusal to undertake EM this year may still be, in the eyes of the uncertain beholder, worthwhile—if some uncertainty can be reduced in the meantime.

Delay begins to make even more sense in the presence of strategic behavior. For example, assuming—again, without asserting—that in the context of this model, the U.S. were the

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[122] For a discussion, see Wara & Victor, *supra* note 42.

[123] U.S. Deputy Envoy for Climate Change Jonathan Pershing, Remarks at the Center for Strategic and International Studies (Jan. 14, 2010) (transcript available from E&ETV at http://www.eenews net/tv/transcript/1091) (". . . Bolivia, Venezuela, Nicaragua, Cuba. These are countries that are a part of the ALBA group, a group that sees this process not so much as a solution to climate change, but, in fact, as a mechanism to redistribute global wealth.").

[124] Lisa Friedman & Darren Samuelson, *Hillary Clinton Pledges $100B for Developing Countries*, CLIMATEWIRE, Dec. 17, 2009, http://www.eenews net/climatewire/2009/12/17/archive/1?terms=hillary+clinton.

party more interested in avoiding climate change, it may seek to delay mitigation to see whether China will undertake EM, and then see if over time some of the uncertainty disappears, or if it can evaluate the feasibility of a side payment under a smaller number of conditions. The possibility of side payments and the introduction of information asymmetry as to whether a country is truly unwilling to undertake mitigation without a side payment presents a variety of problems. If a country believes it can take advantage of an information asymmetry and extract a side payment, it can create all kinds of mischief, and potentially harm its own prospects—assuming the country is genuinely interested in mitigating to avoid climate change.

B. *Adaptation and Geo-engineering*

"Adaptation" is the general term for a wide range of things that can be done by a country to adjust to life in a climate-changed world.[125] Adaptation could include, for example, relocation of populations so that an increased frequency of tropical storms would no longer swamp the population and necessitate a costly rescue and relief response, relocation of agriculture or the genetic modification of seeds to yield more drought-resistant crops, or the construction of sea walls to protect a city from the intruding sea.

"Geo-engineering" measures aim to reduce the atmospheric concentration of greenhouse gases directly, without addressing the sources of the greenhouse gases, thus solving the mitigation problem by avoiding it entirely. Still in its early developmental stages, proposed geo-engineering measures have included: the promotion of ocean algal growth, which would capture carbon dioxide from the atmosphere; the launching of tiny particle-sized mirrors into the upper stratosphere so as to reflect sunlight and prevent it from reaching the Earth; and the creation of synthetic trees that are able to sequester greater amounts of carbon dioxide.[126] Much more innocuous geo-engineering measures include the painting of roofs white, so as to reflect sunlight more effectively and increase the amount of heat that is bounced off the Earth's surface and radiated back out into space.[127] Obviously,

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[125] *See supra* note 76.

[126] For a general discussion of geo-engineering, see HENSON, *supra* note 16, at 330–32.

[127] *See* Mark Henderson, *Professor Steven Chu: Paint the World White to*

these and any future geo-engineering ideas will have their own environmental consequences, which would need to be evaluated and compared with the effects of climate change itself.

For better or for worse, adaptation and geo-engineering have been, at various times and to various degrees, viewed as alternatives to mitigation. These would have the advantage of reducing the country's reliance on others in coming up with a strategy to address climate change. For countries with the resources to do so, both adaptation and geo-engineering could substitute in full or in part for efforts to reduce greenhouse gases.

Unsurprisingly, controversy has surrounded both adaptation and geo-engineering. If it became clear that adaptation or geo-engineering offered a less costly or less complicated option than mitigation, then countries would likely divert resources away from mitigation efforts and towards adaptation efforts. Similarly, geo-engineering poses a threat of draining resources away from mitigation. This is a bitter pill for environmental organizations to swallow—the concession that environmental preservation may not be the best strategy, and that money and attention may move away from mitigation (i.e., preservation) efforts. Moreover, many industrial interests, large and small, have become heavily invested in a low-carbon future. From General Electric, one of the world's largest industrial conglomerates, which has invested heavily in wind turbine technology, to Owl Power, a three-person Boylston, Massachusetts-based company that converts cooking grease into electricity for restaurants,[128] many of the world's industries have already started to rebuild an economy predicated on mitigation as the dominant response to climate change. These interests as well would naturally view adaptation and geo-engineering skeptically. After a period of initial controversy, objections to adaptation seem to have abated, as it becomes clear that climate change is already occurring,[129] and especially when it is couched as aid to less developed countries. Geo-engineering remains radioactive in

Fight Global Warming, TIMES (London), May 27, 2009, *available at* http://www.timesonline.co.uk/tol/news/environment/article6366639.ece.

[128] *See About Owl Power Company*, VEGAWATT, http://www.vegawatt.com/about/ (last visited Nov. 24, 2010).

[129] *See, e.g.*, W. Neil Adger, *Social Capital, Collective Action, and Adaptation to Climate Change*, 79 ECON. GEOGRAPHY 387, 387–88 n.1 (2003); David Noble, *Getting Started on Adaptation to Climate Change*, 116 MUN. WORLD 5, 8 (2006).

many quarters.[130]

In the context of this article's game, adaptation and geo-engineering can be modeled as alternatives to mitigation, and doing so yields some additional insights. The costs of adaptation and geo-engineering, if they can be estimated, may serve as an *upper bound* to the damages of climate change. This does require the heroic (but illustrative) assumption that adaptation or geo-engineering would be effective in placing a country's future population in as good a position as it would in a world without climate change. But a country losing faith in the international process for agreeing to mitigation measures may decide that other approaches are worth investigation.

In this game, A and B can be viewed conceptually as not just the damages from climate change, but the *minimum* of: (1) the damages from climate change; (2) the costs of full adaptation; and (3) the costs of effective geo-engineering. Of course, no adaptation response or geo-engineering scheme can satisfy the heroic assumption that they can provide a social welfare status that is fully equivalent to the complete avoidance of climate change. But a country could rationally ask itself whether it was cheaper to find ways to mitigate (reduce the emission of greenhouse gases), or to find ways to adapt to and live with the effects of climate change, or to geo-engineer itself out of its current climate predicament. And once a country had made such a determination, it could begin to move resources to the best of the three strategies.

If conceptually, A or B is the *minimum* of: (1) damages from climate change; (2) the costs of adaptation; or (3) the costs of geo-engineering, then A and B could well be lower than originally assumed in this model. A country would view its choices, appropriately discounted, as (1) mitigation measures to reduce greenhouse gas emissions; (2) adaptation measures; (3) geo-engineering; and (4) doing nothing and suffering the damages from

[130] *See, e.g.*, Martin Bunzl, *Researching Geoengineering: Should Not or Could Not?*, 4 ENVTL. RES. LETTERS (Oct.–Dec. 2009), http://www.iop.org/EJ/article/1748-9326/4/4/045104/erl9_4_045104.html. *But see* H. Damon Matthews & Ken Caldeira, *Transient Climate – Carbon Simulations of Planetary Geoengineering*, 104 PROC. NAT'L ACAD. SCI. 9949, 9949 (2007), *available at* http://www.pnas.org/content/104/24/9949.abstract ("It is perhaps not surprising that there has been recent renewed interest in possible top-down technological fixes of the climate/energy problem . . . .").

climate change.[131] This introduces another threat to cooperation: the possibility that some countries may start to think that adaptation and geo-engineering are alternatives to cooperation.

Again, returning to an earlier theme, the hint that a country might adapt or geo-engineer would send an alarming signal to other countries. In a game where cooperation and interdependence are the keys to mitigating climate change, the mere suggestion that a country may be less enthusiastic about mitigation is enough to encourage defection. In the arithmetic and vernacular of this game, if a country were to flirt with adaptation or geo-engineering, it might be indicating that its perception of its damages might be lowered by one of these strategies, and that it might be more difficult for another country to believe that Ax or By might be large enough to sustain a cooperative Nash equilibrium. In particular, adaptation costs, to the extent that they are incurred in the future, would be discounted and might seem more attractive than present-day mitigation measures. And to repeat a disclaimer made earlier, this article takes as its starting point the proposition that allowing climate change to advance unchecked is an inefficient global assumption of risk, but this model could well accommodate the conclusion that the most efficient outcome is a non-cooperative one, particularly if adaptation or geo-engineering measures can play a role in substituting for mitigation.

Adaptation and geo-engineering also threaten the prospect for cooperation in mitigation in yet another way: they could induce a search to lower adaptation or geo-engineering costs, thereby further reducing the prospects for cooperation. So it could be that if China engages in posturing before period 1 in order to induce a side payment, the U.S. could eschew EM, and switch research resources from mitigation to adaptation. In the process, the U.S. could figure out how to lower its adaptation costs, and in turn truly make itself and other countries inclined to avoid mitigation altogether. Adaptation and geo-engineering can thus derail international mitigation cooperation by channeling research and development resources away from mitigation.

There is, however, for those hoping for cooperation, a positive contribution to be made by adaptation and geo-engineering.

131 It would be hard to believe, however, that a country would not find at least *some* adaptation measures worthwhile, and thus rule out doing absolutely nothing.

Adaptation and geo-engineering may play a role in facilitating cooperation by curbing strategic behavior. The root of strategic behavior is an imbalance in the ways that countries perceive their own damages from climate change. If, under uncertainty, China is prone to overestimate U.S. damages A and the prospects for an American side payment, then an alternative to mitigation that effectively caps A could serve to dampen such over-optimism. In effect, adaptation and geo-engineering are, by creating alternative avenues of reducing damages, objective ways of calling the bluff of would-be strategically-behaving countries. Given the potential for mischief caused by strategic behavior, this could be a very important feature of adaptation and geo-engineering. This dynamic, while unappealing to those hoping for cooperation, may explain some of the push especially for geo-engineering.

Given the difficulty of achieving cooperation for mitigation, adaptation and geo-engineering would naturally earn the ire of environmental organizations and internationalists still hoping for a global pact. But since glaciers seem to be melting at a faster rate than the rate at which international climate negotiations seem to be proceeding, it is also natural for countries to entertain alternatives to international agreement on mitigation. Adaptation and geo-engineering become off-ramps for getting out of the collective action problem, and freeing a country from obsessing over whether other countries will cooperate in mitigation or free-ride.[132] Adaptation and geo-engineering become ways of hedging and of diversifying a country's portfolio of responses to climate change.

C. *Modeling More Than Two Players*

The proposed game is composed of two players and incorporates a very strong assumption about free-riding: *any* free-riding is fatal to cooperation. This strong assumption is consistent with the results of the WITCH model, which finds that cooperating coalitions must achieve near-universality of mitigation in order to be effective.[133] Certainly, WITCH confirmed that no possible coalition can be effective in avoiding climate change if it lacks

[132] Geo-engineering, to the extent that it could be effectively undertaken by a single country, would clearly solve collective action problems, even as it introduces other externalities, both positive (removing greenhouse gases from the atmosphere) and negative (the negative side-effects of geo-engineering measures).

[133] Bosetti et al., *supra* note 52, at 27.

either the U.S. or China.[134] But expanding the model in this article to simulate negotiations among many countries, not just two, is still illustrative. It should be no surprise that even adding a third or fourth player to a game in which success must be a joint product drives the likelihood of successful cooperation down sharply. Imagine Figure 2, the matrix of outcomes of the game under perfect information, only in three dimensions, or four, or more. It is not difficult to imagine that as the dimensions increase, the chances of cooperation decrease, as the green box in the matrix becomes the green cube in an even bigger cube, and so on.

To take a simple numerical example, even if one were generously to assume that there was, say, a 75 percent chance that each country would mitigate, needing just 5 countries to sign on would reduce the joint product to a mere 10 percent. In light of those odds, any individual country could be forgiven for lacking the stomach even to undertake modest EM measures. Cooperation is much more difficult to achieve in a multi-player game.

Expanding the game to multiple players also further amplifies the importance of signaling. As discussed above in Part IV.A.1, signaling not only plays an important role in conveying information, but the importance of those signals are compounded when we allow for more game-playing stages. Because cooperation is a joint product, any information that may indicate one player is less likely to cooperate will in turn make it less attractive for the other player to cooperate, and so on. And to the extent that an ill-advised attempt to extract a side payment sends a signal to the rest of the world about a country's willingness to mitigate, it creates a potential for defection to snowball.

With more players in the mix, it becomes apparent that a signal becomes still more consequential. A signal in a game with more players would reverberate and have a greater effect on more decision environments. Negative signals in a multi-player game would multiply the disruptive effect on cooperation in mitigation. Again, applying the strong free-riding assumption of this model—that *any* free-riding is fatal to cooperation—the probability of cooperation is a joint product of the probability that *every* country will find it in its interest to resist free-riding and cooperate. In such an environment, a negative signal has the effect of changing the decision environment for *all* of the other countries, lowering

[134] *Cf. id.*

the probabilities of cooperation for all of the other countries, which in turn makes it even less likely that LM will seem to be a rational course of action for *any* of the other countries.

For those that have been critical of the meekness of various measures proposed thus far,[135] this game holds some lessons. With cooperation such a fragile proposition, and with even small signals playing important roles in each country's decision environment, this game illustrates how important even small EM measures might be in salvaging some prospects for future cooperation. Cooperation in mitigating greenhouse gas emissions might necessarily have to consist of a series of small steps.

D. *Other Strategies to Enhance Cooperation*

Almost everything that can be done to the model has the effect of discouraging cooperation. But assuming (without arguing) that as a normative matter this would be a bad outcome—that adaptation and geo-engineering are red herrings and that climate change is truly dangerous enough to warrant costly and concerted efforts to avoid it—then countries would still be well-advised to try to cooperate, and to reach an international agreement to reduce greenhouse gases. In addition to highlighting the pitfalls facing mitigation, this model suggests some strategies that may encourage cooperation in mitigation.

One recent phenomenon that has emerged in international climate negotiations is shaming. Increasingly, a moral stigma has attached to those countries perceived as interfering with an international process to reduce emissions. In 2007, during multilateral negotiations over a successor to the Kyoto Protocol, an American objection to language inserted by China and India was greeted with a now-famous response from the representative of Papua New Guinea:

"I would ask the United States, we ask for your leadership . . . [b]ut if for some reason you're not willing to lead, leave it to the rest of us . . . . Please get out of the way."[136]

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[135] For example, on the weakness of pledges put on the table as part of the Copenhagen summit, Alden Meyer of the Union of Concerned Scientists has this to say: "The pledges put on the table to date do not put us on track to meet that goal and will make it very difficult for us politically and technically beyond 2020 to meet that target." John M. Broder, *Most Countries Submit Emission Reduction Targets by Deadline*, N.Y. TIMES, Feb. 2, 2010, at A10.

[136] Andrew Revkin, *Issuing a Bold Challenge to the U.S. Over Climate*, N.Y.

The ensuing thunder of applause embarrassed the United States representative, Paula Dobriansky, into dropping her objection. The New Guinea representative acknowledged that the portrayal of the United States as the pariah in these negotiations was orchestrated by China and India by introducing measures that were known beforehand to be objectionable to the United States.[137] Nevertheless, the effect of that famous incident has been to raise the costs of countries seeking to scuttle international agreement on emissions reduction. Recently, China and India themselves seem to have become more sensitive to criticism for holding up climate negotiations.[138]

What does moral stigma mean for countries reluctant to mitigate? In this game, it can be added into the damages of climate change. The model is straightforward in that the higher the damages of climate change for a country, the more likely that country will mitigate. If a group of countries are willing to *punish* non-mitigators somehow—perhaps by opposing international initiatives favoring the non-mitigators—then it is possible that non-mitigation might be deterred. In the vernacular of this game, countries can find geo-political ways of increasing A or B.

Instead of a mere moral stigma that is manifested as future geo-political opposition, mitigating countries may opt to use international trade, either as a carrot or a stick, to encourage cooperation in mitigation. As a stick, trade measures such as "border tax adjustments"[139] that seek to levy a tax on imports (and

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TIMES, Jan. 22, 2008, at F2 (Statement of Kevin Conrad, Representative from Papua New Guinea).

[137] Revkin, *supra* note 136.

[138] For example, both countries have recently joined the Copenhagen Accord. China has announced it will voluntarily reduce its carbon intensity by 40 to 45 percent by 2020, compared with 2005 levels. India will reduce its carbon intensity by 20 to 25 percent by 2020, compared with 2005 levels, excluding its agricultural sector. John M. Broder, *Climate Goal is Supported by China and India*, N.Y. TIMES, Mar. 10, 2010, at A9.

[139] A border tax adjustment is a levy on imported goods that are meant to equalize certain tax burdens. Under Article II of the General Agreement on Tariffs and Trade (GATT), only "direct taxes" that can be attributed to an immutable characteristic of a traded good may be the subject of a border tax adjustment. Sales taxes generally fall into this category. Taxes that can be less easily calculated and attributed to a particular good would generally not be legal under the GATT. For a fuller explanation and an analysis of the trade-legality of border tax adjustments, see Joost Pauwelyn, *U.S. Federal Climate Policy and Competitiveness Concerns: the Limits and Options of International Trade Law* (Nicholas Inst. for Envtl. Policy Solutions, Working Paper No. 07-02, 2007),

a subsidy on exports) when mitigating countries trade with non-mitigating countries may play a role in encouraging cooperation. A prevalent domestic concern with regulating greenhouse gases has been the effect on domestic industries, as they compete in the international market with industries in countries that may not regulate greenhouse gases. This is of particular concern with industries that are energy-intensive, such as steel, cement, aluminum, and basic chemicals.[140] While the legality and desirability of using trade sanctions to force non-cooperators into cooperation has been debated and generally rejected,[141] the abject failure of countries to make any significant progress in reaching international agreement might cause some to re-think this approach. This is especially true because the common assumption that border tax adjustments are GATT-illegal has, of late, been analyzed with some greater care and questioned.[142] It may be that border tax adjustments would survive scrutiny by the World Trade Organization after all. If so, they may represent an important tool in bringing countries into an international agreement to cooperate in mitigating greenhouse gas emissions. If nothing else, they could provide political cover for leaders that have to face down domestic industries that might oppose cooperation in mitigation.

A safer course would be to use trade measures as a carrot. Despite being contrary to the letter of the GATT,[143] free trade zones, such as that created by the North American Free Trade Agreement, have proliferated. Creating a "club good" by linking trade liberalization among countries cooperating in mitigating to reduce greenhouse gas emissions stands a stronger change of

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available at http://www nicholas.duke.edu/institute/ internationaltradelaw.pdf.

[140] *See, e.g.*, TREVOR HOUSER ET AL., LEVELING THE CARBON PLAYING FIELD 42–46 (2008) (noting that of these carbon-intensive industries, aluminum and cement face significant pressure from imports, which satisfy a relatively high fraction of demand).

[141] *See, e.g.*, BARRETT, *supra* note 10, at 388–89 (criticizing the use of border tax adjustments, and arguing that they would be hard to calculate and have never been an effective means of enforcing international environmental obligations).

[142] *See, e.g.*, Pauwelyn, *supra* note 139.

[143] Article 1 of the General Agreement on Tariffs and Trade, the so-called "Most Favored Nation" clause, provides that "any advantage, favour, privilege or immunity granted by any contracting party to any product originating in or destined for any other country shall be accorded immediately and unconditionally to the like product originating in or destined for the territories of all other contracting parties." General Agreement on Tariffs and Trade art. 1, Oct. 30, 1947, 61 Stat. A-11, A-12, 55 U.N.T.S 194, 198.

surviving WTO scrutiny than a trade sanction. Although the economic effects are similar, international trade law seems to view such carrots as more benign than sticks, such as sanctions.[144]

Perhaps even less intrusively, countries might participate in the effort to advance the science of climate change, and perhaps even adaptation and geo-engineering. The psychological biasing effect of uncertainty has tilted countries (and their human policymakers and leaders) towards inaction. Participating in the IPCC, which has a continuing role in reducing scientific uncertainty, is necessary but not sufficient. However great the pains that the IPCC has taken to present scientifically credible evidence and findings, it has still been relentlessly attacked for the inevitable missteps that occur given the magnitude of its undertaking.[145] Surveys suggest that the world public seems to overestimate the uncertainty of the scientific conclusions of the IPCC and other climate scientists.[146] As noted above, many industry groups have been funding efforts to emphasize the uncertainty, if not to actively mislead the world public.[147] Whatever the cause, the awarding of a Nobel Prize to the IPCC

[144] Free trade agreements would arguably be inconsistent with the most favored nations clause of the GATT except that, under certain conditions, they are explicitly exempted. Article XXIV of the GATT defines a "free trade area" as "a group of two or more customs territories in which the duties and other restrictive regulations . . . are eliminated on substantially all the trade between the constituent territories in products originating in such territories." Special Protocol Relating to Article XXIV of the General Agreement on Tariffs and Trade, Mar. 24, 1948, 62 Stat. 2013, 2015, 62 U.N.T.S 56, 62 (amending General Agreement on Tariffs and Trade art. 24 § 8(b), Oct. 30, 1947, 61 Stat. A-11, 55 U.N.T.S 194).

[145] Recently, the IPCC was criticized for a misstatement on the rapidity at which Himalayan glaciers are melting. Lauren Morello, *IPCC Admits Error on Himalayan Glacier Warning*, E&E NEWS PM, Jan. 20, 2010, http://www.eenews net/eenewspm/2010/01/20/archive/3?terms=IPCC+admits+error. The IPCC acknowledged that it erred in placing too much reliance upon a 1999 interview with an Indian glaciologist, in predicting that Himalayan glaciers would melt by the year 2035. However, the IPCC emphasized that the overall conclusion regarding accelerating melting in the Himalayas was unchanged by the embarrassment and still consistent with current science. *See* IPCC Statement on the Melting of Himalayan Glaciers (Jan. 20, 2010), *available at* http://www.eenews net/features/documents/2010/01/20/document_pm_04.pdf.

[146] Matthew C. Nisbet & Teresa Myers, *Twenty Years of Public Opinion About Global Warming*, 71 Pub. Opinion Q. 444, 453 tbls.13 & 14 (2007) (showing that people generally believe there is controversy and disagreement among scientists about global warming).

[147] *See* McCright & Dunlap, *supra* note 43, at 348.

might be viewed as an attempt to shore up the IPCC's international standing and perhaps reduce the mistaken public impression that the conclusions of the IPCC are less certain than they actually are. In any case, broader and deeper research efforts into climate science are unlikely to be money wasted, as these could shed light on some extremely important and poorly understood questions we have about our planet. But more importantly, better science can improve the decision environment for climate policymakers.

Finally, another interesting path forward has been suggested by a fiction writer; it can find some support from the lessons of this game: a bilateral agreement between the U.S. and China—not as proxies or representatives for others, but as the actual individual countries—on a cooperative mitigation strategy. The novel *Ultimatum,* by Matthew Glass, takes place in the future and begins with a newly-elected U.S. president that is contemplating the continuation of secret bilateral negotiations with China, essentially as an end run around a failed Kyoto process. The reasoning, as put forward by Glass, is that agreement between two superpowers removes the holdout problems inherent in the Kyoto process and removes the many distractions that have made international agreement so intractable.[148] Bilateral agreement is considerably easier than multilateral agreement, and, once the U.S. and China agree, then a powerful coalition of the two largest greenhouse gas emitters and probably the two most powerful countries could use its economic and political clout, including its two votes on the United Nations Security Council, to induce other countries to cooperate. If they could actually act in concert, the U.S. and China could considerably raise the political and economic costs of non-mitigation. This would especially be true if the U.S.-China coalition could count on the support of the European Union, which has led mitigation efforts and efforts to reach international agreement on mitigation. What the Glass idea does is break down the intractable game of international climate negotiations into smaller, more manageable parts that may be less vulnerable to some of the game-theoretic dynamics modeled in this game, such as strategic behavior.

Is this fanciful fiction or a creative (if Machiavellian) way forward? Countries engaged in international politics do not currently seem to have an appetite for such unilateralism,

[148] GLASS, *supra* note 93, at 48–51.

particularly given the questionable international legality of some inevitable aspects of such an approach. But this could change if damages from climate change begin to crystallize and show themselves to be catastrophic risks. If the exigency of climate change became sufficiently clear, and international climate diplomacy continued to fail, trade law could well turn a blind eye towards some heretofore questionable trade practices.

There are countless ways in which countries can change the payoffs of other countries in their approach to climate change and affect the prospects for cooperation in mitigation. What this Article argues is that they are best understood not as moral urgings or attempts to construct an international legal order that compels adherence through an expression of common interests, but as attempts to affect the decision environment for other countries. The history of international climate diplomacy seems to indicate that those who approach climate negotiations as an intellectual battleground of ideas in which they expect to prevail will be sorely disappointed.

CONCLUSION

Scott Barrett and others have already persuasively argued that it was a mistake to use the Montreal Protocol's phase-out of ozone-depleting chemicals as a template for reducing greenhouse gas emissions.[149] But the way forward is not entirely clear, in light of the efforts that have already been expended in pursuing a multilateral agreement on reducing greenhouse gases, and in light of the disappointing results thus far. This Article does not propose a policy path, for an individual country or for the world community of nations. Rather, of the countless ideas and proposals that have already been raised, this Article attempts to make some sense of some of them.

This Article began with an argument that a new theory of international climate negotiations was needed and then set out to provide one. In its very simple form, the theory described in this Article describes the decision environment for each nation considering mitigation measures to reduce greenhouse gas emissions as consisting of four simple factors: (1) its perceived damages from climate change; (2) its costs of mitigation; (3) the

[149] BARRETT, *supra* note 10, at 2.

rate at which it discounts the welfare of future generations; and (4) the prospect of other countries agreeing to mitigation measures to reduce greenhouse gas emissions.

The simple cost-benefit framework is not meant to be a normative prescription for national decisionmaking; Martin Weitzman's cautionary note about cost-benefit analysis as a determinative decisionmaking tool is important to observe. However, Weitzman's warning notwithstanding, the model does present a reasonable description of how politicians and policymakers actually consider mitigation measures to reduce greenhouse gas emissions. Added to this simple model are a number of factors unique to climate change which increase the complexity but do not fundamentally change the decision framework: scientific uncertainty and imperfect information with respect to how a country perceives its damages from climate change (which gives rise to strategic behavior and poses risks of suboptimal failures to cooperate), the costs and likely effectiveness of adaptation measures and geo-engineering measures (which serve to limit a country's perceived future damages from climate change), and most importantly, the myriad of things that countries can do to change the decision environment for other countries.

On the one hand, the game-theoretic model in this article illustrates, perhaps even dramatizes, the powerful effect of even the threat of defecting (not reducing greenhouse gas emissions). The mere possibility that one country may refuse to mitigate increases the chances that another country will refuse to mitigate, which in turn increases the chances that still other countries will refuse. Early actions to mitigate are thus important not only because they reduce the future cost of late mitigation, but because they create an environment where cooperation is made easier. That free-riding is such a difficult problem and that agreement is a joint product of almost every single major emitter in the world is the primary cause of despair for those hoping for multilateral agreement on reducing emissions.

On the other hand, the risks of just hunkering down and preparing for a potentially much warmer world are frightening enough for many countries that some will consider allowing climate change to affect international relations in other ways. For now, the only costs nations seem to be willing to impose upon those perceived as blocking international agreement is a mild moral stigma. In the future, nations may feel differently about linking a variety of international issues with the issue of climate change. For example, if some nations continue to push for international agreement on reducing emissions, it is hard to imagine that they will rule out using international trade to assemble coalitions and encourage cooperation, legal or not.

While the architects of international efforts to reduce greenhouse gas emissions struggle to obtain agreement from most of the 192 nations of the world, some perspective may be useful on the myriad of things that are being done. Much international discussion has centered upon how to get countries to agree, or at least seem amenable to agreement. Obtaining buy-in from former and current high-emitting recalcitrants such as the United States, China, India, and others, from developing countries that seem to hold the key to developed country participation, and from environmentalists and scientists throughout the world, has seemed to be a Sisyphean task. The goal of this article has been to cast these actions and discussions in a game-theoretic light, and to explain in part their motivations. As well, the winnowing of all of the variables of climate change down to just four—damages, mitigation costs, discount rates, and the prospect of other countries' cooperation—helps policymakers and analysts keep their eye on what it is that can change a country's decision environment.

The central insight of this Article is that countries' decision environments are highly interdependent. The interdependency of climate decisions is what has been missing from previous analyses of international climate negotiations. What this Article does is model these interdependencies. Rolling all of them into one model would make the model intractable; the contribution of this model is to build upon a relatively simple base model and simulate each of these interdependencies separately. Explication of this point beyond the rudimentary illustrations of this Article would require considerably more analysis and computation, but the simple insights in this Article would seem to be of value to a policy community that has devoted much effort to looking at countries and greenhouse gas problems as if they were to be analyzed in isolation from each other. Rather than explicitly model the second-, third-, and higher-order effects, this Article aims to demonstrate that such thinking is much needed. The enormous, all-encompassing importance of the climate change problem demands at least a complete set of analytical tools for understanding why countries and people do the things they do.

Appendix A

Derivation of conditions of perfect information outcomes (Figure 2)

As a first step, the conditions are derived for cooperative Nash equilibria in each of the four subgames. Even though in perfect information the outcomes are pre-ordained for subgames A, B, and C, it is useful to solve the game under different conditions to see when non-cooperation results, and when the parties enter the different subgames.

As an illustration, consider Subgame A. In order for the U.S. to LM, it must be true that its payoffs of LM exceed that of not mitigating:

$-1-2x > -1-Ax^2$

which reduces to the simple condition

$Ax > 2$

Similarly, in order for China to choose to LM, it must be true that $By > 2$. And in order for there to be cooperation—where both parties choose to LM—each country must *believe* that these conditions are satisfied for the other country. If either country did not believe that the condition was satisfied for the other country, it would not believe the other would LM, and hence would not itself undertake the cost of LM, since *both countries* must LM in order for the world to avoid climate change damages. Hence, the only way that a cooperative solution—both countries LM—can be a Nash equilibrium is if *both* of the following conditions $\boldsymbol{Ax > 2}$ and $\boldsymbol{By > 2}$ are satisfied, and both countries *believe* that both conditions are satisfied.

Undertaking a similar solution analysis of Subgame B (where the U.S. undertakes EM but China does not), the U.S. will only undertake LM if the payoffs of LM ($-1-4x$) exceed the payoffs of not mitigating and accepting climate change ($-1-Ax^2$), which reduces to the condition $Ax > 4$. The only way that a cooperative solution—both countries LM—can be a Nash equilibrium is if *both* of the following conditions are satisfied, and both countries *believe* that both of the conditions are satisfied:

$\boldsymbol{Ax > 4}$ and $\boldsymbol{By > 4}$.

The same result obtains in Subgame C, where China undertakes EM but the U.S. does not.

In Subgame D, where neither the U.S. nor China undertakes

EM, the only way that a cooperative solution—both countries LM—can be a Nash equilibrium is if *both* of the following conditions are satisfied, and both countries *believe* that both of the conditions are satisfied:

$\boldsymbol{Ax > 6}$ and $\boldsymbol{By > 6}$.

The conditions for a cooperative Nash equilibrium in each of the subgames are summarized in the table below.

Conditions for Cooperative Nash Equilibrium

Subgame A	$Ax > 2$ and $By > 2$
Subgame B	$Ax > 4$ and $By > 4$
Subgame C	$Ax > 4$ and $By > 4$
Subgame D	$Ax > 6$ and $By > 6$

Under perfect information, the solution to subgames A, B, and C are all the same: cooperation in avoiding damages from climate change. Conceptually, this is because under perfect information each player knows whether ultimately the other player will cooperate, and if there is no possibility that the other player will cooperate, neither player would bother with EM. Therefore subgames A, B, and C would never take place.

Formally, consider the U.S.'s decision environment (the same analysis can clearly be done for the China side). If the U.S. does EM, then it must, knowing what China will do in each period, have determined its payoff of EM was greater than not doing EM. Assume first that China is the type to do both EM and LM, meaning that the parties are in Subgame A. That means that the U.S. prefers outcome 1 to outcomes 3 and 5 (outcomes 2 and 4 do not occur because China will EM):

$-1-2x > -4x$ and $-1-2x > Ax^2$

or, in other words,

$x > ½$ and $Ax > 2 + \frac{1}{x}$

so on the U.S. side the condition for a cooperative Nash equilibrium $Ax > 2$ is necessarily satisfied, since the condition $Ax > 2 + \frac{1}{x}$ is a more stringent one.

Now suppose China was the type to not do EM but do LM (the U.S. knows that China has a perception of high damages but a low discount factor), meaning that the parties are in Subgame B. This means the U.S. prefers outcome 2 to outcome 4 and outcome

5, or:

$-1-4x > -6x$ and $-1-4x > Ax^2$

or, in other words,

$x > ½$ *and* $Ax > 4 + \frac{1}{x}$

so that on the U.S. side the condition $Ax > 4$ for a cooperative Nash equilibrium in Subgame B is necessarily satisfied.

And finally, if China was the type to do neither EM nor LM, the U.S. would never do EM.

Now turning to a formal derivation of the conditions for a cooperative Nash equilibrium shown in Figure 2, consider the illustrative case ***Ax > 6* and *4 > By > 6***. It becomes necessary to solve the game by backward induction. Each of the subgames is solved and then the conditions for entering the subgames are derived.

If the parties are in Subgame A, a cooperative Nash equilibrium occurs, because all that was necessary was that $Ax > 2$ and $By > 2$. The same is true for subgames B and C. If the parties are in Subgame D, however, China will not LM and the parties will not cooperate, and climate change will occur.

The next step in backward induction is to ask which subgame the parties will enter.

Case 1: $x > ½$ and $y > ½$. The parties will enter Subgame A—both parties will EM because their discounted payoffs in A are greater than in any other subgame.

For the U.S.:

$-1-2x > -4x$ because $x > ½$ so A is better than C

and therefore:

$-1-2x > -1-4x$ so A is better than B

and also therefore:

$-1-2x > -6x$ so A is better than the cooperative outcome in D. The solution to Subgame D is non-cooperation, because $By < 6$, but we still know that A is better than the non-cooperative solution to D because $Ax > 6$, so we know $-1-2x > -6x > -Ax^2$.

For China, the same analysis applies, except that the last step cannot be inferred, because $By < 6$. However, we know that:

$-1-2y > -4y > By^2$ because $y > ½$ and because $By > 4$.

So for $Ax > 6$, $4 < By < 6$, $x > ½$ and $y > ½$, the solution is a cooperative outcome in Subgame A.

Case 2: $x > ½$ and $y < ½$. The parties will enter Subgame

B—only the U.S. will EM, but both parties will LM because its discounted payoffs in B are greater than in any other subgame.

For the U.S.:

$-1\text{-}4x > -6x > Ax^2$ because $x > ½$ and because $Ax > 6$ so B is better than D.

For China:

$-4y > -By^2$ because $By > 4$, so B is better than D,

and

$-4y > -1\text{-}2y$ because $y < ½$ so B is better than A.

So for $Ax > 6$, $4 < By < 6$, $x > ½$ and $y < ½$, the solution is a cooperative outcome in subgame B.

Case 3: $x < ½$ and $y > ½$. The parties will enter Subgame C—only China will EM but both parties will LM because its discounted payoffs in B are greater than in any other subgame.

For the U.S.:

$-4x > -6x > Ax^2$ because $Ax > 6$ so C is better than D.

For China:

$-1\text{-}4y > -6x > By^2$ because $y > ½$ and because $By > 4$, so C is better than D.

So for $Ax > 6$, $4 < By < 6$, $x < ½$ and $y > ½$, the solution is a cooperative outcome in subgame C.

Case 4: $x < ½$ and $y < ½$. The parties will enter Subgame D, and neither party will LM.

For China:

$-1\text{-}4y < -6y$ because $y < ½$ so D is better than C, and

$-1\text{-}2y < -4y$ because $y < ½$ so B is better than A

If D is better than C and B is better than A, then China will never EM.

For the U.S., the same is true—D being better than B and C being better than A also means that the U.S. will never EM.

The parties will thus enter Subgame D, and the outcome will be non-cooperation because $By < 6$, so China will not LM, and knowing this, the U.S. will not LM.

So for $Ax > 6$, $4 < By < 6$, $x < ½$ and $y < ½$, the solution is a non-cooperative outcome in Subgame D.

Case 4 is nevertheless an interesting case because there is an unstable Nash equilibrium involving both players doing both EM and LM. None of the conditions above establish that:

$-1\text{-}2x < -Bx^2$ or that $-1\text{-}2y < -By^2$

And if somehow both parties were able to coordinate and agree to do EM, then the parties would actually enter Subgame A where they would rationally both do LM, since we know that $Ax > 6$ and $By > 4$. The problem is that doing the EM to enter Subgame A is a classic prisoner's dilemma—the dominant strategy for both players is to defect, or avoid EM. If China knows that the U.S. will EM, then China's dominant strategy is to not EM. Symmetrically, this is true of the U.S. as well.

A similar analysis can be undertaken to solve the game by backward induction for each of the other possibilities of *Ax* and *By*, and examining for each case what happens under different assumptions of pairs of *x* and *y*. It can be seen that intuitively, the discount factor falling below ½ means that the country will not EM. Depending on values of *A* and *B,* then, a cooperative Nash equilibrium may or may not occur.

Appendix B

Derivation of conditions for feasibility of a period 1 side payment.

Suppose that:

$Ax > 6$ and $By < 2$

Referring to Figure 2, the outcome would be non-cooperation and no mitigation whatsoever. The U.S. would not EM, because it knows that China will do nothing to mitigate.

However, if Ax is large enough, then the U.S. could afford a large-enough side payment to induce China to undertake EM and LM. A side payment could put both the U.S. and China into Subgame A.

For the players to be in Subgame A it must be true that in period 1:[150]

$-1-2x > -Ax^2$ and $-1-2y > By^2$ **(3a)**

And once in Subgame A, in order for there to be a cooperative Nash equilibrium, it must be true in period 2 that:

$Ax > 2$ and $By > 2$ **(3b)**

Conditions 3a and 3b must be satisfied in order for both the U.S. and China to do both EM and LM. But since we are assuming that $By < 2$, at least initially there is no Chinese appetite for mitigation, so there would be no cooperative Nash equilibrium. But if the U.S. would be willing to make a side payment in the amount of ***s*** so that:

$-1-2x-s > -Ax^2$ and $-1-2y+s > -By^2$ **(4a)**

putting the players in Subgame A, and also (dividing through by $-x$ and $-y$ to reflect that the side payment was made in an earlier period, and must be backward-discounted):

$Ax > 2 + \frac{s}{x}$ and $By > 2 - \frac{s}{y}$ **(4b)**

so that once in Subgame A, a cooperative Nash equilibrium obtains. So the game would play out with both players happily and efficiently undertaking both EM and LM, with payoffs of

$\{-1-s-2x, -1+s-2y\}$.

150 In addition to these conditions, the discount rates must be low enough so that Subgame A is preferred to the other subgames. For illustrative purposes, this condition is assumed to be true. Whether discount rates are actually low enough would not change the nature of the analysis of whether side payments would be made or not.